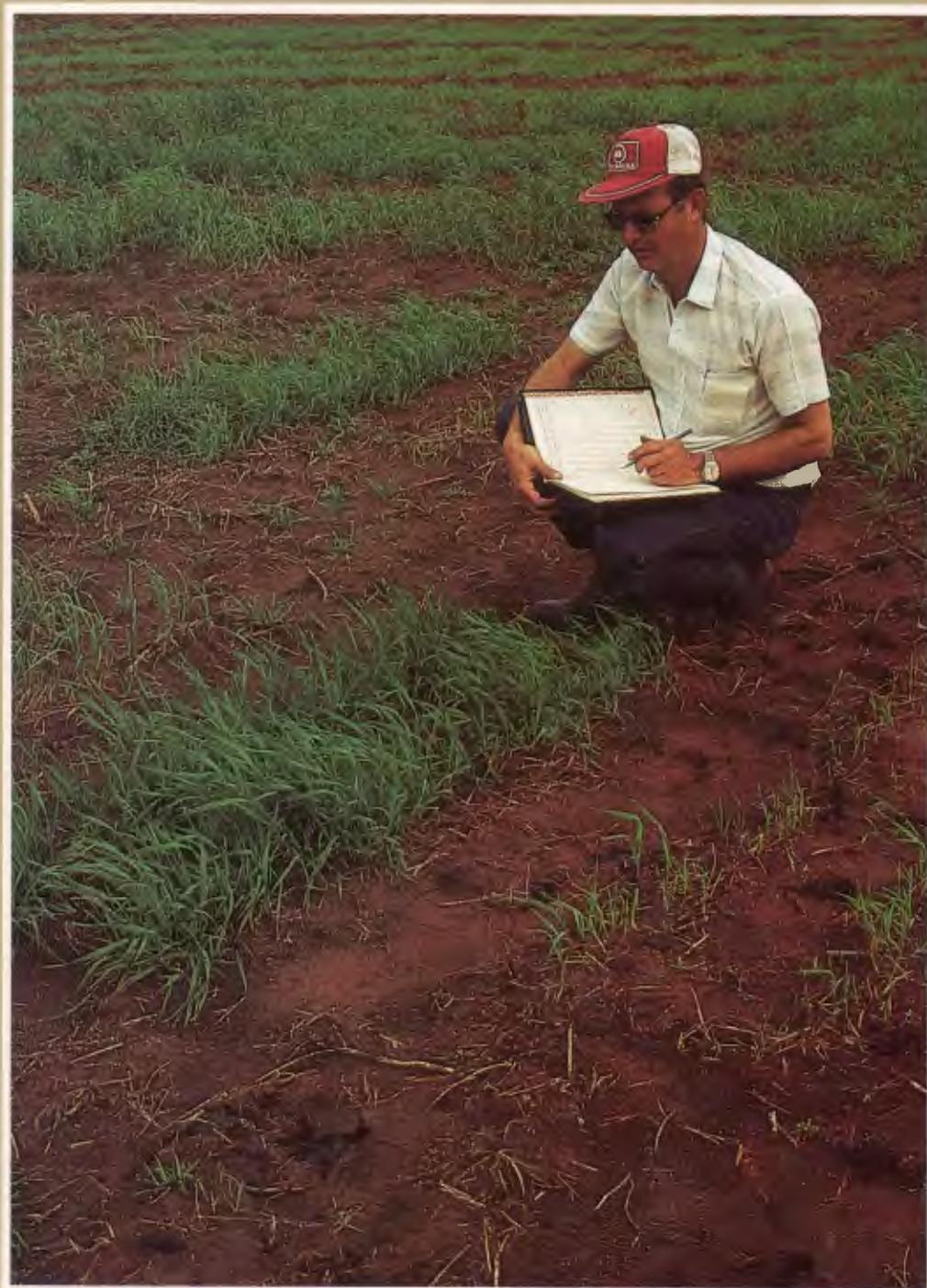

Wheat Breeding for Acid Soils



Review of Brazilian/CIMMYT Collaboration, 1974-1986

M.M. Kohli and S. Rajaram, technical editors

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The International Maize and Wheat Improvement Center (CIMMYT) is an internationally funded, nonprofit scientific research and training organization. Headquartered in Mexico, the Center is engaged in a worldwide research program for maize, wheat, and triticale, with emphasis on food production in developing countries. It is one of 13 nonprofit international agricultural research and training centers supported by the Consultative Group on International Agricultural Research (CGIAR), which is sponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). Donors to the CGIAR system consist of a combination of 40 countries, international and regional organizations, and private foundations.

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On the cover: Ricardo Matzenbacher, wheat breeder at FECOTRIGO's Research and Experimental Center (CEP), checks advanced lines in the aluminum screening plots at Cruz Alta, Rio Grande do Sul. Directly in front of him is CEP 8530, an aluminum tolerant line, and to his left is Suzhoe F3 #1, a highly aluminum-susceptible line. (Photo: Gene Hettel)

TABLE OF CONTENTS

Foreword, Byrd C. Curtis	iv
Preface, M.M. Kohli and S. Rajaram	v
FECOTRIGO's Strategy for Breeding Wheat with Tolerance to Aluminum Toxicity, R.G. Matzenbacher	1
Current Special Breeding Projects at the National Research Center for Wheat (CNPT), EMBRAPA, Brazil, Ottoni de Sousa Rosa	6
Germplasm Exchange Program Between OCEPAR and CIMMYT and Wheat Breeding for Soils with Aluminum Toxicity, Fernando Gomide, Francisco Franco, and Manoel Bassoi	13
Development of Wheat Cultivars with Higher Yield and Adaptation to Different Agroclimatic Conditions of Paraná, Carlos Roberto Riede and Luiz Alberto Campos	26
Photos of some of the principal scientists involved in the Brazilian-CIMMYT collaboration and of wheat production in Brazil, Gene Hettel	35
Wheat Breeding at the Campinas Agronomic Institute, Carlos Eduardo de O. Camargo and João Carlos Felício	39
Developing Bread Wheats for Acid Soils through Shuttle Breeding, Sanjaya Rajaram, Wolfgang Pfeiffer, and Ravi Singh	50
CIMMYT's Laboratory Method for Screening Wheat Seedling Tolerance to Aluminum, Jaime Lopez-Cesati, Evangelina Villegas, and Sanjaya Rajaram	59
The Brazilian Institutions that Collaborate with CIMMYT, Gene Hettel	66

Foreword

One of the important objectives of the International Maize and Wheat Improvement Center (CIMMYT) is to develop high-yielding spring cereals for the acid soil areas existing in several important wheat-producing areas of the developing world. Many of these acid soil areas occur in Latin America, but these soils also present production constraints on other continents, particularly in some of the rainfed areas at higher altitudes in Africa.

Acid soils usually occur in regions of higher rainfall where forests or savannas were the native vegetation. Frequently, the incidence of diseases affecting cereal crops is also high in such environments. Excess aluminum ions in the soil coupled with diseases have been major factors in restricting the performance of earlier CIMMYT germplasm in acid soil areas.

In the 1960s, CIMMYT became aware of the ability of Brazilian wheat germplasm to tolerate the effects of aluminum toxicity and diseases under acid soil conditions. Also evident was the low yield capacity and tall, weak straw of the Brazilian varieties. Little was known about the genetic and physiological basis of aluminum tolerance and screening techniques for breeding were yet to be developed.

CIMMYT entered into scientific dialogue with Brazilian wheat scientists in the late 1960s and early 1970s about possible methods for combining aluminum tolerance with the high-yield characteristics of the Mexican germplasm. A cooperative program between CIMMYT and Brazilian institutions resulted. This cooperation includes the shuttling of segregating germplasm (resulting from Mexican x Brazilian crosses) between Brazil and Mexico and annual visits of CIMMYT and Brazilian scientists to each others sites to select useful materials. By the early 1980s, significant progress was recognizable toward combining traits for aluminum tolerance, disease resistance, and shorter, stiff straw.

This workshop brought together leading Brazilian and CIMMYT scientists involved in this research to review and share experiences and to merge knowledge for exacting greater efficiency for future research cooperation. These proceedings surely will contribute to the scientific knowledge needed to develop improved wheats for the food deficit areas of the world.

This research has been made possible by the cooperative research attitude of the scientists involved, the forward-looking research institutes of Brazil, and the support to CIMMYT by the Consultative Group on International Agricultural Research.

Byrd C. Curtis
Director
CIMMYT Wheat Program

Preface

Through the decade of the 1960s and into the early 1970s, while both area and production of wheat were on an increase in Brazil, the country did not enjoy the benefits of the "miracle seed" of Mexican varieties that were creating a "green revolution" elsewhere in the world. The foremost restriction on the adaptation of the early semidwarf wheats from Mexico to Brazil was their extreme susceptibility to toxic levels of aluminum and manganese and phosphorus deficiency encountered in the acid soils of the region.

In spite of heavy applications of industrial lime to neutralize the acidic effects and also help boost the growth of the soybean crop during the summer season, "crestamento" (crop burning) remained a serious problem for Mexican germplasm. By the mid-1970s, it became clear to CIMMYT breeders that Brazil was not an isolated case with acid soil problems, in fact many other wheat growing regions in Africa and Asia had similar problems.

The first steps to combine the tolerance of Brazilian wheats to aluminum toxicity with the semidwarf stature, high yield potential, and wide adaptation of the Mexican wheats were taken in the mid-1970s. The informal collaborative shuttle breeding relationship between Brazil and CIMMYT started in 1974 through the efforts of N.E. Borlaug, then director of the CIMMYT Wheat Program and scientists at the National Research Center for Wheat (CNPT) of the Brazilian Agricultural Research Enterprise (EMBRAPA), the Rio Grande do Sul Federation of Wheat Soybean Cooperatives (FECOTRIGO), and the Organization of Paraná State Cooperatives (OCEPAR). Later this collaboration was expanded to include the Paraná Agronomic Institute Foundation (IAPAR), the Cerrados Agricultural Research Center (CPAC) of EMBRAPA, and the Campinas Agronomic Institute (IAC).

Under this shuttle breeding operation, crosses between the two germplasm pools (Brazilian and Mexican) are made at both ends and subsequent generations are alternated and selected under local soil and disease pressures. To speed this process up, in the late 1970s, CIMMYT's aluminum screening laboratory began operation at El Batán to enable the screening, in Mexico, of segregating and advanced lines for tolerance to aluminum.

Sometimes the materials of the same generation are grown simultaneously in Brazil and Mexico. Notes on tolerance to aluminum are telexed to Mexico to permit selection for disease and agronomic characteristics only among the lines already determined to be aluminum tolerant.

After 12 years of collaboration, many breeding advances have been made, including the transfer of the aluminum tolerance gene to the semidwarf wheats. This has resulted in new Brazilian varieties that have a yield potential 30% over that of the old varieties under Brazilian conditions while maintaining the aluminum tolerance characteristic.

In the early stages of this collaboration, the major benefactors of this work have been the Brazilian institutions. However, in view of the vast areas worldwide with soil acidity, the Brazilian institutions and CIMMYT agree they should share the responsibility for distributing the germplasm resulting from this collaboration to other countries with acid soil problems.

Representatives of EMBRAPA, FECOTRIGO, OCEPAR, IAPAR, IAC, and CIMMYT met August 13-15, 1986, at Foz do Iguaçu, Paraná, Brazil to evaluate the results of over a decade's collaboration. The second objective of the meeting was to analyze the need to continue with the shuttle breeding efforts to further develop germplasm with a higher degree of aluminum tolerance and to identify additional limiting factors to the development and spread of high yielding wheat varieties in both traditional and newly-opened acid soil regions. The papers in these proceedings report on the breeding progress and plans for the future.

Further research to improve the resistance of the new germplasm to climatic factors such as drought, heat, and frost as well as to diseases and insect pests is essential to broaden future adaptation. A new look into the needs of crop management research for the marginal production areas will help develop technologies that will allow the new germplasm to reach its potential.

We hope that the deliberations at this meeting will not only increase the collaborative work between the Brazilian institutions and CIMMYT, but also will lead to the participation of many other wheat scientists facing similar problems around the world. Today's shuttle breeding program may be the beginnings of tomorrow's shuttle breeding network.

M.M. Kohli
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Technical editors

FECOTRIGO'S STRATEGY FOR BREEDING WHEAT WITH TOLERANCE TO ALUMINUM TOXICITY

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Introduction

In Rio Grande do Sul, wheat has been cultivated since the state's colonization. Average yields vary from year to year due to the many existing problems, which interfere, individually or collectively, with the crop. The main limiting constraints to wheat production are listed below.

Soil

Around 70% of the wheat area under cultivation in the state has high levels of toxic aluminum and low pH. Even though a great quantity of lime has been used, the pH of the soil has not yet been corrected in most of the areas under wheat cultivation. The natural soil fertility is low and most of the soils are deficient in phosphorus. Excessive preparation of the soil results in poor structure and creates compaction which inhibits normal water penetration and root development.

Diseases

The diseases that normally occur and cause yield losses, in order of importance in recent years are glume blotch (*Septoria nodorum*), leaf rust (*Puccinia recondita*), common root rot and leaf spot (*Cochliobolus sativus*), leaf blotch (*Septoria tritici*), scab (*Gibberella zeae*), powdery mildew (*Erysiphe graminis tritici*), common wheat mosaic virus, barley yellow dwarf virus, and loose smut (*Ustilago tritici*).

Agronomic characteristics

Agronomic problems include tall cultivars with weak straw, small spikes with low fertility, reduced tillering, and spike sprouting.

Insects

Major insect pests in Rio Grande do Sul include aphids (mainly *Rhopalosiphum padi*, *Schizaphis graminum*, *Metopolophium dirhodum*, and *Sitobium avenae*), wheat caterpillar (*Pseudaletia adultera* and *Pseudaletia sequax*), ants (*Atta* spp. and *Agromyrmex* spp.), rhizophagous insects (*Phytalus sanctipauli*, *Diloboderus obderus*, *Pantomorus* sp., and *Conoderus scalaris*), borers (*Listronotus bonariensis* and *Diabrotica speciosa*), and green stink bug (*Nezara viridula*).

Weeds

Weeds are important in wheat production, mainly in fields grown for seed. Among the weeds, the ryegrass (*Lolium multiflorum* L.), wild buckwheat, (*Polygonum convolvulus* L.), raphanus, (*Raphanus raphanistrum*), and oats (*Avena* spp.) are some of the most important.

Frost

Late frosts, occurring during the flowering period, are very frequent and destructive.

Historical Background of FECOTRIGO's Wheat Program

Aware of the limiting factors to wheat production in the state and of the need for more research to solve them, the Rio Grande do Sul Federation of Wheat and Soybean Cooperatives (FECOTRIGO) started the Accelerated Wheat Improvement Program (PAT) in 1969, through an agreement with the State Secretary of Agriculture in Julio de Castilhos. The program's goal was to release wheat cultivars with higher yield potential and stability. In 1971, PAT was terminated but its work continued at Cruz Alta (latitude 28°38'21", longitude 53°36'42", altitude 473 masl), the site of FECOTRIGO's Research and Experimental Center.

Breeding Methodology

Research is conducted in an area under crop rotation where wheat is not cultivated for a 3-year period. To develop new cultivars, simple crosses, top crosses, multiple crosses, and back crosses are made.

The crosses are made according to the following scheme.

Simple crosses

Brazilian Wheat x Introduced Wheat (bridge for top or multiple crosses);
Brazilian Wheat x Brazilian Wheat.

Top crosses

Brazilian Wheat x Introduced Wheat x Brazilian Wheat; Brazilian Wheat x
Brazilian Wheat x Brazilian Wheat.

Multiple crosses

(Brazilian Wheat x Introduced Wheat) x (Brazilian Wheat x Brazilian
Wheat); (Brazilian Wheat x Brazilian Wheat) x (Brazilian Wheat x Brazilian
Wheat).

F₂ generation

Sown in soil with aluminum toxicity in plots spaced out in four rows of 5 m.
Plants tolerant to aluminum are bulk selected. About 640 F₂ lines were sent
from CIMMYT during the 1980-86 period.

F₃ generation

Sown in limed soil in plots of two rows 3 m long with a normal plant
population. Plots are bulk selected. More than 7000 F₃ lines were sent from
CIMMYT during the 1980-86 period.

F₄ generation

Sown in limed soil, in plots spaced out in three rows of 5 m. In this
generation, preselection for foliar diseases is done; the final selection is made
of individual plants. Nearly 1000 lines were sent from CIMMYT during the
1980-86 period.

Advanced generations (F₅, F₆, F₇, and F₈)

Sown in limed soil in plots spaced out in four rows of 5 m. In these generations, preselection for foliar diseases is also done; final selection is made of individual plants or bulk. About 3100 advanced generation lines were sent from CIMMYT during the 1980-86 period.

New lines

New lines are placed in Preliminary Yield Trials and again evaluated for tolerance to aluminum toxicity to confirm their reactions. Only tolerant material is selected for continued evaluation in yield trials.

Summer generation

Since 1973, a summer generation has been planted in Ciudad Obregon, Mexico, through the seeding of primarily F₁ and advanced lines. In some years, new crosses are made.

CIMMYT-FECOTRIGO Cooperative Program

Since the beginning of the FECOTRIGO's wheat improvement program, an intense interchange of germplasm has been maintained with CIMMYT. Through the years, many CIMMYT nurseries have been sown in Cruz Alta. In 1986, the following nurseries were sown in Cruz Alta.

International trials

ISWYN--International Spring Wheat Yield Nursery

ESWYT--Elite Spring Wheat Yield Trial

IBWSN--International Bread Wheat Screening Nursery

ISEPTON--International Septoria Observation Nursery

HLSN--Helminthosporium Screening Nursery

IDTN--International Disease Trap Nursery

SSN--Scab Screening Nursery

LRRM--Leaf Rust Resistant Material

LACOS--Lineas Avanzadas del Cono Sur

Nurseries for evaluating tolerance to aluminum toxicity

ATSN--Aluminum Tolerance Screening Nursery. More than 900 lines in this nursery have been sent from CIMMYT during the 1980-86 period.

ATDRM--Aluminum-Tolerant and Disease-Resistant Material. Some 676 lines of this material were sent from CIMMYT during 1980-86.

Segregating populations

Segregating populations resulting from Mexican x Brazilian crosses made in Mexico are first selected for tolerance to aluminum toxicity in the laboratory. Material selected in the laboratory is sent to Brazil for planting and field selection. Alternate selections are made in Cruz Alta and Ciudad Obregon.

Due to low adaptation to the climatic conditions in Cruz Alta, only 845 of 9286 fixed lines (9%) received from CIMMYT were selected during the 1980-85 period. These selected lines have been incorporated into the FECOTRIGO breeding program.

However, the importance of the CIMMYT-FECOTRIGO cooperative program is evident. During the 1979-86 period, material sent by FECOTRIGO to Mexico for planting included 2172 F₁ lines, 931 advanced lines, and 836 CIMMYT-FECOTRIGO segregates. Even though a high percentage of the CIMMYT-FECOTRIGO segregates (segregating populations selected from various nurseries sent to Brazil by CIMMYT) were discarded, the 836 lines sent to Mexico resulting from the alternate selection process is significant.

Over the last 8 years, 1113 of 1331 FECOTRIGO lines (84%) originated from crosses made in Mexico and/or that had selections in Mexico. Another gage of the importance of the cooperative program is demonstrated by the fact that 120 of 197 FECOTRIGO lines (61%) under official testing in Rio Grande do Sul from 1979 to 1986 came out of the cooperative program. In 1985 and 1986, 100% of the FECOTRIGO lines sent for official testing were involved in the cooperative program at some stage.

Results

The number of crosses made, along with the way the segregating populations are handled, has resulted, on average, of around 175 new FECOTRIGO lines each year. This volume allows FECOTRIGO to include between 20 and 25 lines per year in the official yield trials in Rio Grande do Sul. This number of lines represents approximately 30% of the total under test in the state.

Released cultivars

FECOTRIGO's Wheat Improvement Program has released eight cultivars recommended in Rio Grande do Sul and 13 in total when counting other Brazilian states.

PAT 19
S12/J 9281.67
B530-0J-52C-1C-0C
--not recommended since 1983

Nhu-Pora
SA 3423/IAS 57
B7765-6C-3A-2A-0S
--will not be recommended after 1986

PAT 7219
S12/J 9280.67//Nobre/TP
B707-4C-3C-1C-0C

Minuano 82
S 71/S 473.A3.A2
B12598-0A-10A-1A-0A

PAT 7392
J 12326.67/IAS 55
B1809-15C-1A-0Z

CEP 11
PF 6968*2/Hadden
B11950-4Z-1A-1A-0A

Charrua
SA 3423/IAS 57
B7765-6C-3A-2A-0A

CEP 14-Tapes
Pel 72380/Atr 71
B13374-3Z-1A-6A-2A-0A

Lines recommended for other Brazilian states

FECOTRIGO lines tested and recommended for planting in other Brazilian states include:

Paraná--PAT 7219, PAT 7392, Charrua, Minuano 82, Sulino (Pfn/Cno"S"/S 67), CEP 7672 (Pfn/Cno"S"/S 67), CEP 7780 (PF 6968*2/Had), CEP 11, and CEP 13-Guaiba (PAT 19/Ald"S"/Gto/LV).

São Paulo--PAT 72247 (Amz"S"/Tzpp/Son 64) and CEP 7780.

Mato Grosso do Sul--PAT 24 (Nt 67/C25).

Santa Catarina--CEP 11, CEP 14-Tapes, Charrua, Minuano 82, NHU-Pora, and PAT 7392.

CEP 11, CEP 7780, and CEP 13-Guaiba resulted from the CIMMYT-FECOTRIGO cooperative program.

CURRENT SPECIAL BREEDING PROJECTS AT THE NATIONAL RESEARCH CENTER FOR WHEAT (CNPT), EMBRAPA, BRAZIL

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Introduction

Historically, wheat cultivation in the Brazilian states of Rio Grande do Sul, Santa Catarina, and Paraná (southern part) has been low in productivity due to poor cropping systems. However, since the late 1970s, farmer adoption of practices recommended by the South Brazilian Commission on Wheat Research has resulted in yields of up to 3 t/ha. The Commission's recommended technologies include crop rotation, use of better cultivars, chemical disease control, insect control, and seeding rate. The development of a system using these technologies has proved effective in the 1980s and has had positive effects on encouraging the development of cultivars with higher yield potential and changes in fertilization techniques.

This paper summarizes some of the breeding research underway at EMBRAPA's National Research Center for Wheat (CNPT), Passo Fundo, Rio Grande do Sul.

Breeding for Disease Resistance Through Back Crossing

Genes, sources of resistance, and cultivars used as recurrent parent for developing resistance to leaf rust, stem rust, and powdery mildew resistance are listed in Tables 1, 2, and 3, respectively. In addition to these diseases, breeding projects are being conducted to obtain material with better resistance or tolerance to wheat mosaic virus, barley yellow dwarf virus (BYDV), septoria nodorum blotch, septoria tritici blotch, and *Gibberella zea*.

Breeding for Resistance to the Aphid, *Schizaphis graminum*

It has been possible to control the aphids in the southern region rather effectively through the introduction of insect parasites, some of which have adapted very well to the southern Brazil environment. Prior to the introduction of these parasites, wheat farmers in the south region made three to four insecticide applications during the wheat growing cycle; however the number of required applications today is practically zero.

In the warmer regions, however, *S. graminum* continues to be a serious problem in wheat, and demands several insecticide applications during the growing season. Since 1979 CNPT scientists have been incorporating resistance to *S. graminum* into several cultivars with good adaptation to Brazilian ecological conditions. Wheat cultivars, such as Amigo, Largo, and

CI 17959, are being used as sources of resistance. Promising resistant lines, such as PF 84588 (Jup 73*3/Amigo), are already being included in yield trials in Mato Grosso do Sul, Paraná, and São Paulo. Results obtained by Gabriela Tonet from yield trials at Dourados emphasizes *S. graminum* resistance in these regions (Table 4).

Table 1. Genes, sources of resistance, and cultivars used as recurrent parents at CNPT for incorporation of resistance to leaf rust. CNPT/EMBRAPA-Passo Fundo, 1985.

Genes	Sources of Resistance	Cultivars used as recurrent parents
<i>LR9</i>	RL6010, Transfer, CI15143, Oasis, Sullivan, Precoz Parana Inta	BH 1146, BR 10, BR 12, CNT 7, CNT 8, CNT 10, IAC 5-Maringá, Jupateco 73, Londrina E Nombre
<i>LR17</i>	Klein Lucero	BH 1146, Londrina, Jupateco 73, Nobre.
<i>LR18</i>	Africa 43	BH 1146, Jupateco 73, Londrina
<i>LR19</i>	Agatha, CI14048	BH 1146, BR 10, BR 12, CNT 8, CNT 10, IAC 5-Maringá, Jupateco 73, Nombre, Londrina
<i>LR21</i>	RL6043	RH 1146, BR 12, Jupateco 73, Londrina
<i>LR24</i>	Agent	BH 1146, BR 10, BR 12, CEP 11, CNT 8, CNT 10, IAC 5-Maringá, Jupateco 73, Nobre, Sonora 64, Supper X, Londrina
<i>LR25</i>	Transec	BR 14, Nobre, Londrina
<i>LR26</i>	Alondra Sib, Kavkaz	BR 1146, BR 12, CNT 10, IAS 55, Sonora 64, Super X, CNT, Londrina, Nobre
<i>LR29</i>	C75-39	Nobre, Londrina
-	Hadden, CEP 11	BR 12, BR 14, IAC 5-Maringá, Jupateco 73, CNT 7, Londrina, IAS 55
-	Waldron	Jupateco 73, Londrina
-	Amigo, Amigo Sel.	Jupateco 73, Peladinho, BH 1146

Table 2. Genes, sources of resistance, and cultivars used as recurrent parents at CNPT for incorporation of resistance to stem rust. CNPT/EMBRAPA-Passo Fundo, 1985.

Genes	Sources of Resistance	Cultivars used as recurrent parents
<i>SR24</i>	Agent, Tifton	BH 1146, BR 12, CEP 11, CNT 8, CNT 10, Jupateco 73, Londrina, Nobre, IAC 5-Maringá, Sonora 64, Super X, Peladinho
<i>SR25</i>	Agatha, CI14048	BH 1146, BR 20, BR 12, CNT 8, CNT 10, Londrina, Jupateco 73, Nobre, IAC 5-Maringá
<i>SR26</i>	Eagle, Kite	BH 1146, BR 12, Jupateco 73, Super X, Peladinho, IAS 58, Londrina
<i>SR27</i>	WRT238-5	Jupateco 73, IAS 55, Nobre
<i>SR31</i>	Kavkaz, Alondra Sib, ST1	BH 1146, BR 12, CNT 10, IAS 55, Nobre, Londrina, Sonora 64, Supper X, IAS 58, Peladinho, CNT 1
<i>SR32</i>	ER 5155	BH 1146, BR 12, Jupateco 73, Londrina
<i>SR33</i>	ER 5405	BH 1146, CEP 11
-	Amigo, Amigo Sel.	BH 1146, Jupateco 73, BR 10, BR 14, Peladinho, Nobre, IAS 58
-	Pfs 801	BH 1146, Jupateco 73
-	Waldron	Jupateco 73, Londrina,
-	CMH71.567	BH 1146

Table 3. Genes, sources of resistance, and cultivars used as recurrent parents at CNPT for incorporation of resistance to powdery mildew. CNPT/EMBRAPA - Passo Fundo, 1985.

Genes	Sources of Resistance	Cultivars used as recurrent parents
<i>Pm2+Pm6</i>	CI12633	CNT 8, CNT 10, Londrina, Nobre, BR 10, BR 12, BR 4.
<i>Pm2+Mld</i>	HST13471	IAS 55, Londrina, Nobre, CNT 10
<i>Pm4a</i>	CI14123, CI14124	CNT 7, CNT 8, IAS 55, IAS 59, Londrina, Nobre, BR 12, BR 14, Jupateco 73, BH 1146
<i>Pm4b</i>	Weinstephaner	Londrina, Nobre, BR 14
	CI14033	CNT 1
	Hadden	CNT 7, CNT 10, BR 12, BR 14, Jupateco 73, Londrina, IAC 5-Maringá
	Sullivan, Oasis	CNT 10, BH 1146, Londrina, BR 10
	FB6627, FB6628, FB6629, FB6630, FB6631	Londrina, BH 1146, Jupateco 73 BR 10, BR 12, BR 14, CNT 1
	Kenya Leopard	Londrina
	Transec	Nobre, Londrina, BR 14
	PF7727	BR 12, CNT 8
	Tifton	Londrina, BH 1146

Table 4. Yields and relative yield losses observed under field conditions in South Central Brazil (Dourados) with natural infestations of *Schizaphis graminum*. CNTPT/EMBRAPA-Passo Fundo, 1986.

Cultivars	Yield (kg/ha)	Relative reduction in yield (%)
PF84588	1811.75	0
Pavo	1370.69	24.34
IAPAR 1	1223.01	32.49
IAPAR 3	929.45	48.69
IAC 5- Maringá	685.03	62.18
El Pato	656.51	63.76
OCEPAR	603.30	66.70
Jandaia	563.74	68.88
BH 1146	531.03	70.68
PAT 7279	519.88	71.30
Candeias	499.51	72.43
Mindano 82	492.42	72.82
BR 13	459.04	74.66
Nambu	406.14	77.58
LA 1549	399.44	77.95
Amigo Precoce	282.90	84.38
Alondra 4546	263.27	85.46
IAPAR 6	182.79	89.91
Sulino	150.18	91.71
OCEPAR 8	136.13	92.48
Paraguai 281	135.12	92.51
Charrua	112.97	93.76
Anahuac	106.56	94.12
Cocoraque	98.79	94.54
CEP 7672	76.54	95.77
BR 1	0	100.00

Breeding for Phosphorus Utilization in the Soil

Based on the knowledge that the cultivars Toropi and PG 1 have the characteristic of efficiently utilizing phosphorus in the soil, CNPT initiated a breeding project in 1981 to transfer this characteristic to cultivars with high yield potential. The project is also aimed at obtaining cultivars tolerant to aluminum and manganese toxicity (crestamento).

The first backcrosses were made between Toropi (as the donor) and BH 1146, Londrina, CNT 10, Nobre, and Jupateco 73. The segregating material from the F₄ on is being selected in soils with natural fertility, a pH of 4.6, a phosphorus level of 1.0 ppm, a potassium level of 85 ppm, exchangeable aluminum of 2.4 me/100 g, and 4.5% organic matter. Only nitrogen fertilizer is applied. Because this soil is extremely low in pH and phosphorus, plants that have inherited Toropi's phosphorus efficiency characteristic should survive. Some of the material is also grown in soil with better fertility to avoid the loss of the germplasm.

Under identical soil conditions, rye, triticale, and barley cultivars are also being tested. The rye cultivars have shown excellent performance compared to wheat. A small collection of triticales, already recommended or included in the Brazilian yield trials, have performed about the same as the better wheats. The barley cultivars have performed poorly.

The rye cultivars represent material collected from several Brazilian regions where soils are highly acidic and low in phosphorus. Their excellent performance could be attributed to recurrent selection that might have occurred when the population was submitted to natural selection during several generations. In order to utilize the phosphorus efficiency of the Brazilian ryes, Maria Irene B. Fernandez of EMBRAPA is making crosses between Brazilian wheats and Brazilian ryes.

After having determined the good performance of rye in relation to phosphorus uptake, studies were initiated to verify the performance of the CIMMYT-derived variety of Alondra, which carries in its genetic constitution the 1B/1R translocation from rye. Some lines with Alondra in their pedigree also show favorable reaction to phosphorus stress. In a collection of lines derived from the cross BH 1146*6/Alondra, in which stem rust resistance of the Alondra sib had been transferred to BH 1146, it was possible to select some lines with better phosphorus efficiency than BH 1146 itself.

Lines selected for efficient utilization of phosphorus are now available and are being tested to verify the efficiency of the selection methodology. In 1985, some of the material from this project was sown in soil with 12.5 ppm phosphorus, 4.5 pH, and 3.6 mm/100 g aluminum; no phosphorus application was made. The best cultivars for phosphorus, such as Toropi and PG 1, showed excellent growth, whereas IAC 5-Maringá and BR 4, which are aluminum-tolerant cultivars, did not grow well under these conditions. This indicates that Toropi and PG 1 can utilize phosphorus strongly fixed in the soil, whereas other cultivars, though they may be aluminum-tolerant, do not have the same phosphorus extraction capacity. In such cases, the selection for phosphorus uptake efficiency should be easy in acid soils with high phosphorus content, provided phosphorus is not applied at planting.

Considering the extent of phosphorus-deficient soils in the principal Brazilian wheat-growing regions, maximum efforts should be directed to determining the existing genetic variability for phosphorus uptake efficiency. It is also important to develop more efficient methods for selecting plants with this characteristic in the field as well as under laboratory conditions.

Breeding for Sprouting Resistance

Cultivars such as RL 4137, Kleiber, Frontana, Jufy I, WW 9941, and Takahe, have been used as sources of sprouting resistance. Lines with phenotypes very similar to BH 1146, IAC 5-Maringá, CNT 8, and CNT 10, but with better resistance to grain germination in the spike, are already available.

Breeding for Better Tolerance to Frost

CNPT continues to conduct research to develop cultivars with better frost tolerance during the wheat's reproductive phase. Crosses are made with better sources already identified and the segregating material is being field-tested with earlier sowing than recommended for the Passo Fundo region. In this way, the probability of frost occurrence coinciding with the period between flowering and beginning of maturity is increased, thus allowing for the selection of frost-tolerant plants.

Some observations were made after the occurrence of severe frosts in 1984 at Passo Fundo where temperatures were as low as -4.1, -2.2 and 1.9°C. Differences in tolerance among the cultivars used by farmers were confirmed. The cultivar IAC 5-Maringá was one of the most susceptible, whereas CNT 8 showed intermediate tolerance. During the vegetative phase, the cultivars CEP 14, PG 82125, CEP 8236, CEP 8151, CEP 82152, and Coker 762 showed tolerance.

GERMPLASM EXCHANGE PROGRAM BETWEEN OCEPAR AND CIMMYT AND WHEAT BREEDING FOR SOILS WITH ALUMINUM TOXICITY

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Introduction

The Organization of Cooperatives of the State of Paraná (OCEPAR) operates in the western region of the state located at Cascavel and Palotina, two major areas of research. The research Center Eloy Gomes at Cascavel has localized soils with aluminum toxicity (Latossolo roxo distrofico) at an altitude of 760 masl and latitude and longitude of 24°56'S and 53°26'W. The research Center of Palotina is situated in an area of soils without aluminum toxicity (latossolo roxo eutrofico) at an altitude of 300 masl and latitude and longitude of 24°17'S and 53°50'W.

Until 1985, the wheat breeding program for acid soils was conducted only in Cascavel. In 1986, the breeding work was expanded to a site at Guarapuava, located in the southcentral region of the state.

In 1976, Dr. John W. Gibler, then technical director of FECOTRIGO, supplied segregating wheat populations to OCEPAR--some of which originated from CIMMYT. In 1977 Gibler became the research director of OCEPAR and initiated the technical and scientific exchange program with CIMMYT. Since then, OCEPAR technicians have visited CIMMYT (Ciudad Obregon) every year to make crosses and to select material.

Sources of Materials Developed in Soils with Aluminum

At Cd. Obregon, special attention is normally given to selection of the following populations of CIMMYT: segregating populations for aluminum (from F₂ to advanced lines), advanced lines, and F₁ Spring x Spring of CIMMYT origin.

During the last 3 years, 1922 F₁ OCEPAR lines were sent to Cd. Obregon. Out of these populations, OCEPAR scientists selected promising F₂s during the bulk harvest. The F₂ bulk seed was divided across three locations in Paraná: Palotina, Cascavel, and southcentral region of the state.

Another important source of germplasm enrichment includes nurseries sent to Paraná directly by CIMMYT, such as F₂ drought, F₂ Helminthosporium, F₂ Gibberella, F₂ Aluminum Screening Nursery, and lines tolerant to aluminum and diseases. All these populations are tested in acid soils.

OCEPAR Crossing Block: A Source of Variability for Acid Soils

The crossing block is seeded at Palotina where the conditions for artificial crosses in wheat are more favorable. During the last 3 years, the following lines were widely utilized to obtain the segregating populations.

BG/Hork"S"//Aldan"S"

CM48016-P-2M-1Y-3M-0Y-1T-0PR

*Buck Buck"S"

CM31678-R-4Y-2M-15Y-0M-4T-0PR

*Gll/Aust.II 61-157//Cno 66/3/Pvn"S"

CM30326-2M-7Y-3M-1Y-2B-0Y-0PTZ-1T-0PR

Hahn"S"

CM33682-L-1Y-1Y-1M-3Y-100B-503Y-500B-0Y

IAS 636/Ald"S"

CM47042-2T-2T-2T-0P-1T-0PR

IAS 20/H 567.71//IAS 20/3/3*MGA

CMH80A.211-3B-1Y-3B-0Y

IAC 5/Aldan"S"

CM46961-1M-8Y-1M-17PR-3T-0P

PF70402/Ald"S"//PAT72160/Ald"S"/3/Ald"S"/Huac"S"

CM55581-GPR-3T-1T-2T-1P-1P-0T

*Vee"S"

CM33027-F-15M-500Y-0M-68B-0Y-0PTZ-1T-0PR

Aeplogom II 64.27/Pvn"S"

CM42402-30Y-1M-1Y-3M-0Y-0PTZ

Lines above with an asterisk were segregated at Cascavel because of the presence of Al⁺⁺⁺. However, individual plants were selected which were seeded at Cd. Obregon. The best plots were harvested and replanted at Cascavel where the work continues.

Outstanding Mexican Germplasm in Segregating Populations at Cascavel

Analysis of the field book of segregating populations at Cascavel during 1984 and 1985 verifies that Mexican germplasm has contributed to building up lines appearing in variable proportions. Following is the list of the best crosses of some segregating populations.

**List of the best segregating populations (crosses)
F₂ SxS Al segregating population--1984**

Buc"S"/4/PF7040/Ald"S"//PAT 72160/Ald"S"/3/Ald"S"/Huac"S"
CM72332

CNT 8/Dove"S"
CM74241

IAS 64/Aldan"S"//Klt"S"
CM74282

IAC 5/Aldan"S"//GH"S"
CM74323

IAS 54/Bnq"S"//GH"S"
CM74328

Thb"S"/Gen
CM74374

PF70354/Mus"S"//Pjn"S"
CM76606

IAS 58/IAS 55//Ald"S"/3/IAC 5/4/Ald"S"/IAS 58.103A//Ald"S"/5/Vee"S"
CM76622

PF70354/Mus"S"//Tan"S"
CM76607

Thb"S"/Vee"S"
CM76629

CEP 7780/GH"S"
CM76646

Kvz/Cgn//Bow"S"
CM78439

Kvz/Cgn//Lira"S"
CM78441

Jun"S"/3/Gov/Az//Mus"S"
CM78466

IAC 5/Aldan"S"//Mon"S"/Ald"S"
CM78509

IAS 58/IAS 55//Ald"S"/3/IAC 5/4/Ald"S"/IAS 58.103A//Ald"S"/5/Lira"S"
CM78518

IAS 58/IAS 55//Ald"S"/3/IAC 5/4/Ald"S"/IAS 58.103A//Ald"S"/5/PAT
19/Vee"S"/3/PF70354/Como"S"//PAT 7364
CM78523

List of the best segregating populations (continued)

CEP 7780/Ures
CM78534

PF70354/Ald"S"//Bow"S"
CM78565

PF70354/Ald"S"//Vee"S"
CM78566

PF70354/Ald"S"//Lira"S"
CM78570

PF70354/Ald"S"//7/PJ//Cno67/7C/4/Cno67/INIA//Bb/3/Pic"S"//5/
IAC 5/6/Ald"S"//Yr/Trf"S"
CM78579

Thb"S"//Ures
CM78602

IAS 63/Ald"S"//Gto/Lv/5/Ald"S"//3/Fkn/H570.71//Fkn/4/
Mad"S"//CNT 7
CM78608

IAS 63/Ald"S"//Gto/Lv/3/Bnq"S"//CNT 8//Aldan"S"//IAS 58
CM78609

Segregating population F₂ MOC (Y-82-83)--1984

F3.71/Trm//Buc"S"
CM74828

Bjy"S"//Jup//Thb"S"
CM76247

CNT 8/Vee"S"
CM74240

IAS 64/Aldan"S"//Lira"S"
CM76611

Pew"S"//Thb"S"
CM72328

Bow"S"//CEP 7672
CM72370

Bgs/Sort//Kal/Bb/3/Kea"S"
CM76838

Bow"S"//Thb"S"
CM77926

Thb"S"//PF70354/Ald"S"
CM78594

List of the best segregating populations (continued)
F₅ IND segregating population--1984

PF7339/Vee"S"
CM65045-1P-1P-1T

Gjo"S"/Klt"S"
CM62016-1P-2P-2T

Ani"S"/Mad"S"
CM64625-1P-2P-1T

Vee"S"/Ald"S"
CM64672-8P-2P-7T

F₆ IND segregating population--1984

Ald"S"/IAS 58/3/Emu"S"/Kal/Bb
CM60992-DPR-0PR-0P-1P-1P-1T

F₂ IND OC segregating population--1985

CNT 8/Vee"S"/IAC 5/Aldan"S"
CM85271-BPR

OCEPAR advanced lines--1985

IAS 63/Aldan"S"/6/Coc/5/Pch/4/KT54*2/N10B//Kt54/3/Har59
CM51665-F-104PR-4T-7T-2T-1P-1P-3T-1T

IAS 64/Aldan"S"/INIA/Mus"S"
CM51666-C-106PR-2T-4T-3T-1P-1P-2T-1T

Cox/Cow//PF7225/Ti 71/3/Ald"S"
CM55478-BPR-2T-1T-2T-3P-2P-2T-1T

IAC 5/Yd//IAS 64/Al/3/Ald"S"
CM55480-APR-1T-1T-6T-2P-2P-1T-1T

Ald"S"/4/Bb/Gll//Cia/7C/3/Kuz/Ti 71/6/
PJ62//Cia/7C/3/Cia/INIA//Bb/3/Pci"S"/5/PAT 72195
CM58270-A-BPR-2T-1P-1P-3T-1T

Bb/Nor67//Cia"S"/7C/3/Ald"S"/4/Aldan"S"/PAT 7268
CM58276-A-5PR-7T-2P-6P-2T-2T

Pel72380/Atr 71//Thb"S"
CM70396-5M-3Y-2M-2Y-1M-0PR

Vee"S"/Thb"S"
CM72355-(1-23)M-012Y-05M-0PR

PF70354/Ald"S"/IAC 5/Aldan"S"
CM70419-6Y-2M-1Y-016AL-0PR

Some of the Best Advanced Lines at Cascavel

Several of the fixed lines observed in collections and/or preliminary yield trials were outstanding at Cascavel in 1984 and 1985. Following is the list of the best lines of the collections and preliminary yield trials.

Cox"S"/Sis"S"/Trm73/Ald"S" (4 pedigrees)

CM51689-A-103PR-2T-3T-2T-1P-6P-0T

CM51689-A-103PR-2T-3T-2T-5P-4P-0T

CM51689-A-103PR-2T-5T-1T-1P-2P-0T

CM51689-A-103PR-2T-8T-3T-1P-2P-0T

IAC 5/4/INIA"S"/7C//Cia/GH/3/Pci"S"

CM46963-2T-3T-2T-3T-1P-0T

PF70354/3/Era/Cia//7C/5/Ald"S"/4/Kal//Cia/INIA//Cia/Cha

CM47982-E-1M-102PR-2T-1T-1T-3T-4P-6P-0T

IAS 63/Ald"S" (3 pedigrees)

CM53814-1Y-1Y-12M-0Y

CM53814-1Y-1Y-6M-1Y-1M-0PR

CM53814-1Y-1Y-6M-1Y-0M

IAC 5/4/Nad63/Tor//Pch/3/Bli"S"/Mes"S"/5/

PAT 7219*2/Zp"S"//Ald"S"/Emu"S"

CM57616-A-3Y-1Y-4M-2Y-1M-0PR

Bnq"S"/CNT 8//Aldan"S"/IAS 58 (2 pedigrees)

CM58323-K-1Y-2Y-0M-2Y-1M-0PR

CM58323-K-1Y-2Y-0M-3Y-1M-0PR

Kvz/K4500 L.A.4

SWM176-3M-1Y-10Y-2M-0Y-0PTZ-0Y

F3.71/Trm

SWM5704-10Y-1M-3Y-1M-1Y-0B

Mn632131/Pavon76"S"

CM42404-30Y-1M-1Y-1M-1Y-2M-0Y-1PTZ-0Y

JUP//7C/PATO B/3/LR64/INIA 66//INIA 66/Bb/4/Ana

CM37760-C-21Y-2M-1Y-3M-0Y

Ore Fl 158/Fdl//Kal/Bb/3/Nac (2 pedigrees)

CM47634-T-2M-3Y-1M-2Y-1Y-1M-0Y

CM47634-T-2M-3Y-1M-2Y-1Y-2M-0Y

H567.71/3*Pel Atr

CMH77308-1Y-4B-1Y-1B-3Y-1PTZ-0Z

F.12.71/Coc

SWM5784-17Y-1M-4Y-5M-1Y-0B

Some of the Best Advanced Lines at Cascavel (continued)

Yaco"S"

CM41195-A-13M-RY-3M-1Y-1M-0Y

IAS 63/Aldan"S"

CM47046-10M-6Y-16M-1Y-1Y-1M-0Y

IAS 63/Ald"S"//Gto-Lv/3/Ttm"S"

CM70447-2Y-3M-0PR

Aldan"S"/IAS 58

CM53481-6Y-1Y-4M-1Y-0M

Mon"S"/Imu

CM61942-5Y-1M-1Y-1M-0Y

IAS 64/Aldan"S"

CM47207-4M-5Y-1F-701Y-12F-0Y

IAS 58/4/Kal/Bb/Cj"S"/3/Ald"S" (4 pedigrees)

CM50464-4Y-7F-2Y-5Y-104F-0Y

CM50464-12Y-2F-2Y-1Y-3M-1Y-0M

CM50464-12Y-6F-1Y-1Y-7M-3Y-0M

CM50464-4Y-8F-1Y-1Y-102F-0Y

PF 70354/Ald"S"//Mes"S"

CM57597-Z-1Y-1Y-3M-2Y-1M-0Y

Outstanding Lines in Preliminary Trials from Cascavel-- 1984-85 (Equal to or Better Than the Best Local Check)

1984

Her 77/Chat"S"

CM58647-0P-4P-0P

Vee"S"

CM33027-F-3M-3Y-1M-0Y-100Y-0B

Cox/Sis"S"//Trm/Ald"S"

CM51689-A=103PR-2T-3T-2T-2T-1P-0P

1985

Ald"S"/3/Ti 71/Pci"S"//Kvz/5/Nad 63/

Tor//Pch/3/Bh"S"/Mes"S"/4/PAT 72195 (4 pedigrees)

CM58269-K-1PR-3T-1P-2P-0T

CM58269-K-1PR-2T-3P-3P-0T

CM58269-K-1PR-3T-1P-1P-0T

CM58269-K-1PR-3T-1P-3P-0T

Outstanding Lines in Preliminary Trials (continued)

Cox/Sis "S"//Trm/Ald "S" (5 pedigrees)

CM51689-A-103PR-2T-3T-2T-1P-3P-0T

CM51689-A-103PR-2T-3T-2T-1P-6P-0T

CM51689-A-103PR-2T-5T-1T-1P-1P-0T

CM51689-A-103PR-2T-5T-1T-1P-3P-0T

CM51689-A-103PR-2T-8T-3T-1P-2P-0T

IAC 5/Aldan "S" (2 pedigrees)

CM46961-16M-110PR-1T-14T-1T-0P

CM46961-1M-110PR-1T-12T-1T-0P

Npo/Tob//8156/3/Hal/Bb/4/Ald "S"//5/Ald "S"//Pel SL1276.69

CM58261-B-10PR-1T-3P-0P

PF70354/Aldan "S" (2 pedigrees)

CM50487-2T-3T-2P-1P-0T

CM50487-2T-3T-3T-2T-2P-2P-0T

IAS 54/Vee "S"//Backa/Ald "S"

CM54470-FPR-5T-1T-1T-1T-1P-1P-0T

Bjy "S"//Jup

CM40038-21M-1Y-2M-0Y-88M-0Y

Go 4537/Go 38290//Yg 5295/3/Ald "S"

CM53464-7M-1Y-1Y-0Y

Cqt/Az//IAS 55/Ald "S"//3/Ald "S"//Nofn/4/Pjn "S"//Pel SL127.6.69

CM58478-B-2Y-1Y-1M-1Y-0M

Mon "S"//Mn72131

CM52721-5Y-2M-2Y-0M

Kvz/K4500 L.A. 4

SWM176-3M-1Y-10Y-2M-0Y-0PTZ-0Y

Lines Included in the Network of Official Experimentation

After having been analyzed for yield potential in the preliminary yield trials, the best lines received the designation "OC" (lines that underwent selection by the team of scientists of the OCEPAR wheat program) or "IOC" (introduced lines). In 1983, 1985, and 1986, new OCEPAR lines in the network of official experimentation were included. The following list of crosses verifies that the exchange program with CIMMYT has resulted in the development of lines for soils with aluminum toxicity as well as for soils without aluminum problems.

Origin	Cross and Pedigree
IOC 831	Mrs"S"/Coc SWM4127-1Y-1M-4Y-2M-1Y-0M
IOC 832	Bow"S" CM33203-H-8M-8Y-1M-1Y-1M-0Y
IOC 833	Bow"S" CM33203-F-4M-4Y-1M-1Y-0M
IOC 834	Titmouse"S" CM30136-3Y-1Y-0M
IOC 835	Kvz/K4500.L.A.4 SWM176-3M-1Y-10Y-1Y-2M-0Y-0PTZ-0Y
IOC 837	Forlani/Acciaio//Anahuac 75 SWM4578-56M-3Y-3M-0Y
IOC 838	Forlani/Acciaio//Anahuac 75 SWM4578-56M-3Y-3M-2Y-0Y
IOC 839	Kvz/Torim SWM3879-9Y-13M-3Y-1M-0Y
IOC 8310	Hahn"S" CM33682-L-1Y-9Y-1M-1Y-100B-0Y
IOC 8311	Tzpp*2/Ane//INIA/3/Jup/Kvz CM21335-9Y-3M-1Y-1Y-1Y-0B
IOC 8312	Jup 73/Zp"S"//Coc 75 CM37614-B-14Y-4M-1Y-0M
IOC 8313	Veery"S" CM33027-F-8M-1Y-9M-1Y-2M-0Y
IOC 8314	Veery"S"=Glennson M 81 CM33027-P-8M-1Y-8M-1Y-2M-0Y
IOC 8315	Kl.H 645. Y 48000/Jup 73/7/Kal/Bb/5/Cno// Bb/GH/4/I 67//S310/PI 62/3/Lr II 1847/6/Cgn CM36090-I-2M-1Y-3M-2Y-3M-0Y
IOC 8316	Mad"S" CM32586-101M-1Y-1M-0Y
OC 833	IAC 5/Aldan"S" CM46961-13M-103PR-1T-1T-0T

Origin	Cross and Pedigree
OC 834	IAC 5/Aldan"S" CM46961-16M-102PR-6T-5T-0T
OC 835	IAS 64/Aldan"S"//INIA 66/Mus"S" CM51666-C-106PR-1T-3T-0T
OC 837	Ald"S"/3/Era/Son 64//Era*2/4/Ald"S" CMH78.413-9Y-3B-1Y-0T
OC 838	IAS 20/H567.71//IAS 20/3/Ald"S"/4/H570.71/ Era*2//IAS 58 CMH77A.277-11B-2Y-1B-1Y-0T
OC 839	IAS 20/H567.71//IAS 20/3/Ald"S"/4/H570.71/ ERA*2//IAS 58 CMH77A.277-11B-2Y-1B-2Y-0T
IOC 851	Chat"S" CM33090-T-1M-4Y-0M-25B-0Y-2PTZ-0Y
IOC 852	Car 853/Coc 75//Vee"S" CM47556-EE-1M-1Y-2M-1Y-0PR
IOC 853	Fln/Acc//Ana 75 SWM4578-56M-3Y-3M-2Y-0M
IOC 854	Kvz/K 4500 L.A. 4 SWM176-3M-1Y-10Y-1Y-1M-0Y-0PTZ-0Y
IOC 856	IAS 64/Aldan"S"/6/Coc/5/Pch/4/Kt54 ² /NIOB// K54B/3/Nar CM51665-F-2Y-2M-1Y-2Y-0P
OC 851	IAS 54/Vee"S"//Backa/Ald"S" CM54470-APR-4T-1T-4T-0P
OC 852	Ald"S"/PF 72707//PAT 19 CM19547-AA-0M-1L-10IP-4P-0P
OC 853	Ald"S"/PF 72707//PAT 19 CM19547-AA-0M-1L-103P-2P-0P
OC 857	IAS 64/Ald"S" CM47203-0G-1L-8P-1P-0P
OC 858	IAS 58/Bjy//Bnq CM47971-H-1M-109PR-1T-4T-2T-0P
IOC 861	P12.71/Coc SWM5784-17Y-1M-4Y-5M-1Y-0B

Origin	Cross and Pedigree
IOC 862	CNT 7//Kvz/Buho"S"/3/Pel 72390 B22484-S-1M-3Y-3Y-0P
IOC 863	Pel 72243/PAT 7219//Ald"S" B22042-E-1M-1Y-1Y-0P
IOC 864	Hork/Ald"S" CM53468-1M-3Y-1Y-0P
IOC 865	Kal/Bb//Ald"S"/B 7408 CM53596-1M-3F-2Y-0P
IOC 866	Vee"S" CM33027-F-3M-3Y-1M-0Y-100Y-0B
IOC 867	Chat"S" CM33090-N-1M-1Y-0M-121Y-0B
IOC 868	Ald"S"/BH 1146//Ld"S"/Ald"S" F12299-F-6M-1Y-1Y-0Z-0Y
IOC 869	Kn/Bb//Ald"S"/3/PAT 7268 CM53637-10Y-1Y-0Z-2Y-0A
OC 861	PAT 19/Cow"S"//Pel 72242/3/Ald"S" CM55482-5PR-3T-8T-3T-1P-0P
OC 862	Ld/BH 1146//Ald"S"/3/Kvz/093.44//Ald"S" CM55532-APR-2T-2T-1T-1T-2P-0P
OC 863	IAC 5/3/Cia/Pj//Gll/4/IAS 54/Ald"S" B19782-AA-0M-5L-5P-1P-4P-0P
OC 864	Ld/BH 1146//Ald"S"/3/Kvz/093.44//Ald"S" CM55532-EPR-4T-3T-1T-1P-0P
OC 865	PF70402/Ald"S"//PAT 72160/Ald"S"/3/ Ald"S"/Huac"S" CM55581-GPR-3T-1T-11T-1P-0P
OC 866	PF70402/Ald"S"//PAT 72160/Ald"S"/3/ Ald"S"/Huac"S" CM55581-GPR-5T-1T-2T-1P-0P
OC 867	Her77/Chat"S" CM58647-0P-4P-0P
OC 868	Sis"S"/Vee"S" CM58331-0P-1P-0P

Origin	Cross and Pedigree
OC 869	Coxilha/Sis"S"/Trm73/Ald"S" CM51689-A-103PR-2T-3T-2T-2T-1P-0P
OC 8610	Nbo/10B//8156/3/Kal/Bb/4/Ald"S"/5/ Aldan"S"/Pel SL 1276.69 CM58261-B-5PR-2T-2P-0P
OC 8611	IAC 5/Pel 21414.66/E 2631/3/Ald"S" B 17422-4T-2T-4L-5L-0P
OC 8612	Pel 72018/Ald"S" B 16590-6T-1S-3T-1T-0P

Of the lines included in the network of official experimentation in 1983, only two are still in final trials: IOC 834 and IOC 835. IOC 853 has been outstanding in acid soils.

Of the lines tested in 1985, some are already in the final trial (IOC 856, OC 855), whereas others (OC 851, OC 853) remain in intermediate yield trials.

Of lines tested in 1986, ones with outstanding performance in acid soils include: IOC 862, IOC 863, IOC 868, IOC 869, OC 863, and OC 8612.

Recommended Cultivars for Acid Soils Derived from Brazilian x Mexican Crosses

Among the recommended cultivars for acid soils listed below, OCEPAR 11-Juriti is outstanding because of its excellent adaptation and stability at various locations in the state. This should ensure the expansion of this cultivar in the area soon. OCEPAR 11-Juriti has shown better tolerance to aluminum than the cultivar OCEPAR 8-Macuco under field conditions.

OCEPAR 8-Macuco (OC 812)	IAS 64/Aldan"S" CM47207-6M-103PR-2T-0T
OCEPAR 9-Perdiz (OC 8112)	IAS 58/Bjy//Bnq"S" CM47971-A-4M-105PR-2T-0T
OCEPAR 10-Garca (OC 8123)	IAC 5/Aldan"S" CM46961-16M-109PR-1T-0T
OCEPAR 11-Juriti (OC 8148)	IAC 5/Aldan"S" CM46961-16M-113PR-1T-0T

OCEPAR 12-Maitaca
(OC 819)

PF 71124/PAT 72162
B13707-0A-0Z-0L-0M-1L-0P

OCEPAR 13-Acaua
(OC 8122)

IAC 5/3/IAS 20/Pato B//Bb/INIA
B14402-0M-1T-2T-0T

Conclusions

Analysis of this wheat breeding work for the acid soils points to the progress being made with the introduction of Mexican germplasm. The Mexican germplasm is providing a source of higher yield potential, shorter height, increased number of tillers, and rust resistance for the Brazilian germplasm. These are the first signs of positive results from the collaboration between OCEPAR and CIMMYT. In the future, better material will continue to be developed through this joint effort.

DEVELOPMENT OF WHEAT CULTIVARS WITH HIGHER YIELD AND ADAPTATION TO DIFFERENT AGROCLIMATIC CONDITIONS OF PARANÁ

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Introduction

In recent years, the State of Paraná has been contributing annually more than 50% of the Brazilian national wheat production. The productivity in different regions is variable according to the agroclimatic conditions, soil types, and varieties grown. These agroecological variations require that the recommended cultivars be more stable in their productivity.

The wheat breeding activities of IAPAR are concentrated in a project entitled, "Development of Wheat Cultivars with Higher Yield and Adaptation to Different Agroclimatic Conditions of Paraná." This project emphasizes obtaining advanced lines with higher yield potential and stability of production, resistance to diseases and adverse environmental conditions, and acceptable nutritional and baking quality.

The research efforts to realize these objectives are directed towards the introduction and evaluation of germplasm, crossing and selection of advanced lines, implementation of genetic variability through mutation, development of advanced populations through recurrent selection; studies on genetic inheritance of important characteristics, development of basic wheat germplasm with tolerance to drought and aluminum toxicity and resistance to diseases, and evaluation of industrial and baking quality. Finally, experimental work with cultivar yield trials are carried out during different seasons to recommend the best cultivars. Simultaneously, seed of advanced lines and cultivars is multiplied.

Important Characteristics of Wheat Breeding in Paraná

- 1) Breeding to improve yield, yield stability, and wide adaptation.
- 2) Breeding for disease resistance.
 - * Foliar diseases: rusts, helminthosporium, powdery mildew, septoria.
 - * Spike diseases: gibberella and helminthosporium.
- 3) Breeding for agronomic characters.
 - * Short- to medium-height and strong straw.
 - * Crop cycle: longer vegetative and shorter grain filling periods.
 - * Resistance to shattering.

4) Breeding for environmental stress.

- * Tolerance to drought/heat.
- * Tolerance to frost.
- * Resistance to head sprouting.

5) Breeding for soil toxicity and plant nutrition.

- * Tolerance to aluminum toxicity.
- * Tolerance to Mn and Fe toxicity.
- * Efficiency of P extraction system.

6) Breeding for the industrial nutritional and baking quality.

- * Selecting for grain appearance: color and grain filling.
- * Determining protein content, endosperm texture, and water absorption by using "Near Infrared Reflectance (NIR) Analyzer."
- * Evaluating protein quality for baking through the "Sodium dodecyl sulfate" test.
- * Determining protein quality for baking through electrophoresis used for separating the gluten protein into sub-units according to their molecular weight.
- * Determining the activity of Alpha-amylase enzyme, indicating the degree of head sprouting, through the "Hagberg Falling-Number" apparatus.
- * Evaluation of nutritional quality through the determination of levels of protein, amino acids, fat fiber, and carbohydrates.

Breeding Methodology

Development of wheat cultivars with better yield and stability of production

This project involves the introduction and evaluation of germplasm aimed at regional adaptation, selection of genotypes with disease resistance, and environmental stress factors. About 3000 genotypes are annually introduced and evaluated at Londrina, Faxinal, and Ponta Grossa. The major institutions involved for such germplasm exchange are CIMMYT, CNPT, FECOTRIGO, OCEPAR, IAC, UEPAE de Dourados, and CPAC.

In another project, advanced lines are developed with high yield potential and stability along with disease resistance through hybridization and selection in segregating populations. The activities within this experiment cover choice of parents, planning and execution of crosses, selection in segregating populations, and harvesting of uniform lines for the preliminary

yield trials. Normally about 500 crosses are made per year including simple, triple and backcrosses. The modified pedigree method is used to handle the segregating populations, which includes selection of individual plants in the F₂ and F₅ generations and mass selection in the F₃ and F₄ generations. Plots of F₆s are evaluated through the moving mean method and F₇s through the augmented design. The segregating generations are inoculated with major prevalent pathogens, providing ideal conditions for the selection of resistant types: this work is being conducted at Londrina and Palotina.

Development of lines with aluminum tolerance is a project conducted at Ponta Grossa. These lines are genotypes with higher genetic yield potential under unfavorable environments combined with Al toxicity. Selections in segregating populations are done in Al-toxic soils low in phosphorus. The methodology is similar to the experiment described above conducted at Londrina and Palotina.

IAPAR implements genetic variability in wheat through induced mutation. The work is employed in situations where there is little genetic variability for the character to be selected. Some of these characteristics include: reduction in height, earliness, and disease resistance. This work is done at Ponta Grossa and Londrina in collaboration with Centro de Energia Nuclear na Agricultura (CENA).

IAPAR develops populations with recurrent selection, aimed at accumulating genes that control quantitative characters. This recurrent selection work builds populations with a wider genetic base, higher capacity of recombination, thus facilitating selection of genotypes for Paraná's different ecological conditions. Basically, attempts made to develop two types of populations, one with high yield potential and disease resistance, and another with tolerance to Al⁺⁺⁺.

Inheritance of resistance to helminthosporium will be studied using the backcrossing method and utilizing the P₁, P₂, F₁, F₂, RC₁, and RC₂ generations of the crosses between resistant genotypes such as BH 1146, PF 7339 and IA 7956, and the susceptible IAPAR 1-Mitacore. Knowledge about the phenotypic and genotypic variances will help estimate genetic parameters such as heritability, average degree of dominance, and expected genetic progress in selection. The genetic mechanism of the inheritance of phosphorus utilization will be studied using the same method.

Additional support activities to the IAPAR breeding program include:

- * Selection of sources of resistance to diseases.
- * Selection of sources of tolerance to drought.
- * Selection of sources of tolerance to aluminum toxicity.
- * Evaluation of industrial, baking, and nutritional qualities.

Regional experimental work with cultivar yield trials for the subtropical regions of Paraná

The major objectives of this project are to evaluate the performance of wheat germplasm developed by IAPAR and other research institutions and to develop cultivars with high yield potential, resistance to major diseases, tolerance to aluminum, good agronomic type, and with adaptation to the subtropical regions of Paraná (north, west, and southwest).

The advanced lines and/or cultivars will be evaluated annually through preliminary, intermediate, and final yield trials, conducted in soils with aluminum toxicity at Nova Fatima, Faxinal, Congonhinhas, Campo Mourao, Ubirata, Cascavel, Realeza, Pato Branco, and Renascenca, and in soils without aluminum toxicity at Cambara, Londrina, Sertaneja, Floresta, São Miguel do Iguacu, Marechal Candido Rondon, Palotina, and Goio-Ere. The utilization of new cultivars that demand less fertilizer and pesticide will contribute to reducing the cost of production and increasing productivity and profit in the wheat sector.

In 1986 through the joint efforts of IAPAR, OCEPAR, and INDUSEM, 162 experiments were conducted and 238 cultivars were evaluated. Seed of promising lines is multiplied after the second year of collection and continues through the final yield trial in order to maintain sufficient seed stocks for experimentation and the formation of genetic seed lots. Seed multiplication is conducted at the experiment station in Londrina, Palotina, Vila Velha, and Florestal.

Evaluation and selection of cultivars for the agroclimatic conditions of south central Paraná

The objective of this project is to evaluate new wheat cultivars in the different soil conditions of the south central Paraná. We select the more productive ones with good agronomic characters, tolerance to aluminum toxicity and resistance to diseases. The major aim is to diversify the germplasm and increase the yield and stability of cultivars for wheat farmers who use higher technology and are in a majority in this region of the state. Another aim is to select cultivars with the capacity to extract needed nutrients from the soil, especially for small farmers in localized areas where wheat was once an important crop, but now seldom planted. Each year, preliminary, intermediate, and final yield trials will be conducted in soils with low- to medium-fertility at Ponta Grossa, Arapoti, Tibagi, Guarapuava and Irati. Lines included in the trials will be multiplied at Ponta Grossa.

Figures 1-4 show Paraná maps on climate, occurrence of exchangeable aluminum in the soil, the occurrence of soluble phosphorus in the soil, and zones for cultivar recommendations, respectively.

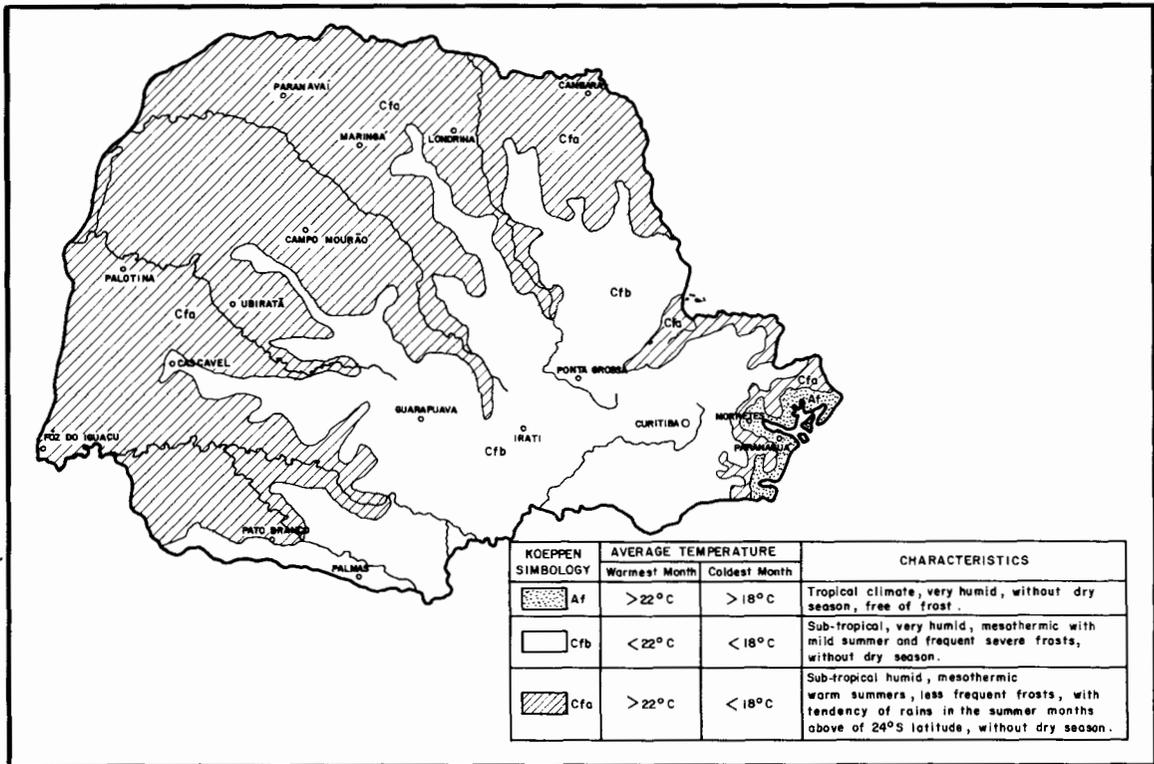


Figure 1. Climatic chart of Paraná State (According to W. Koeppen).
 Source: Manual Agropecuário para o Paraná. IAPAR, 1976.

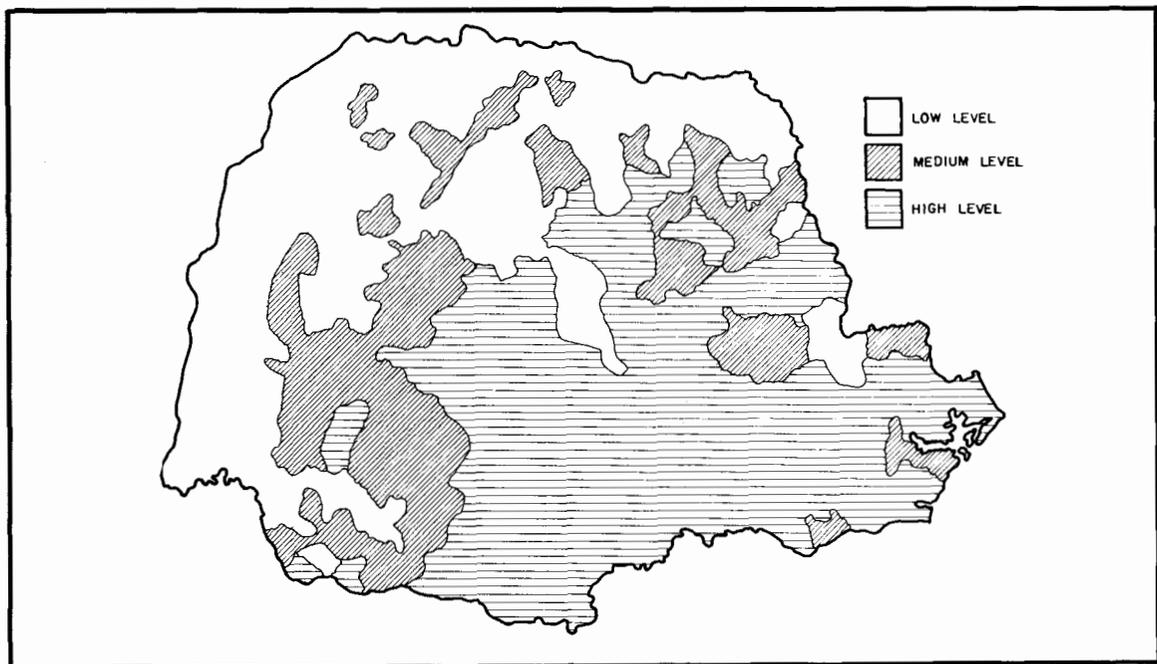


Figure 2. Occurrence of the exchangeable aluminum in the soils of Paraná State.
 Source: Manual Agropecuário para o Paraná. IAPAR, 1976.

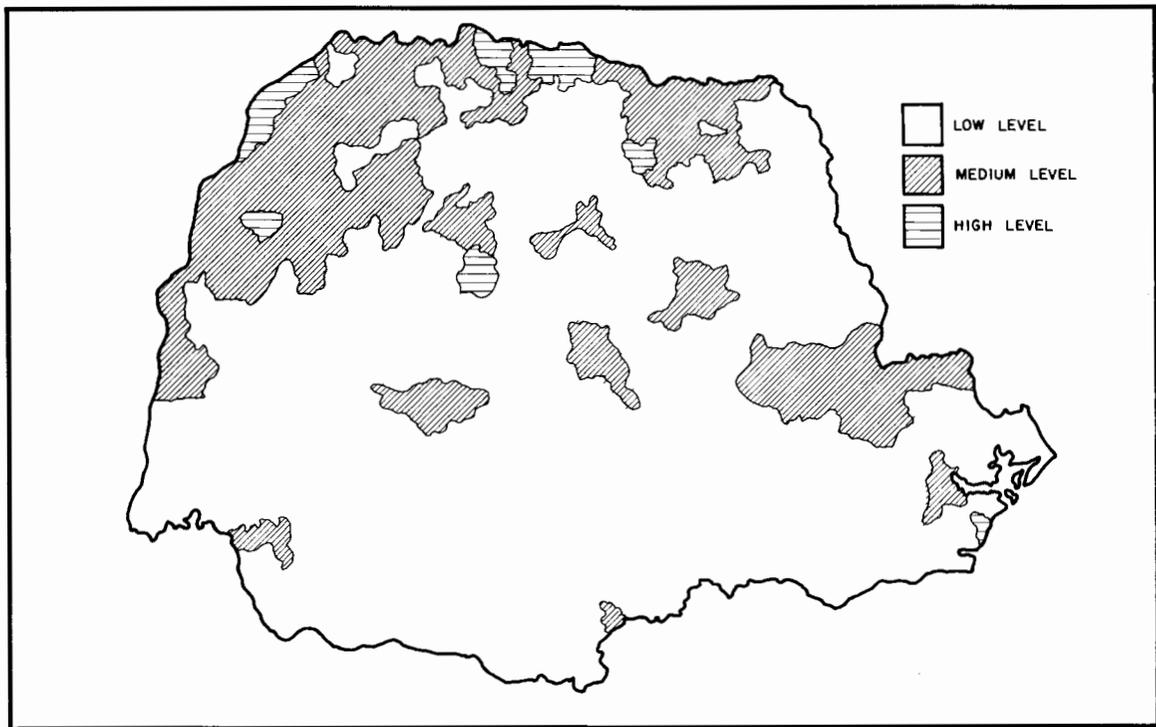


Figure 3. Occurrence of soluble phosphorus in the soils of Paraná State.

Source: Manual Agropecuário para o Paraná. IAPAR, 1976.

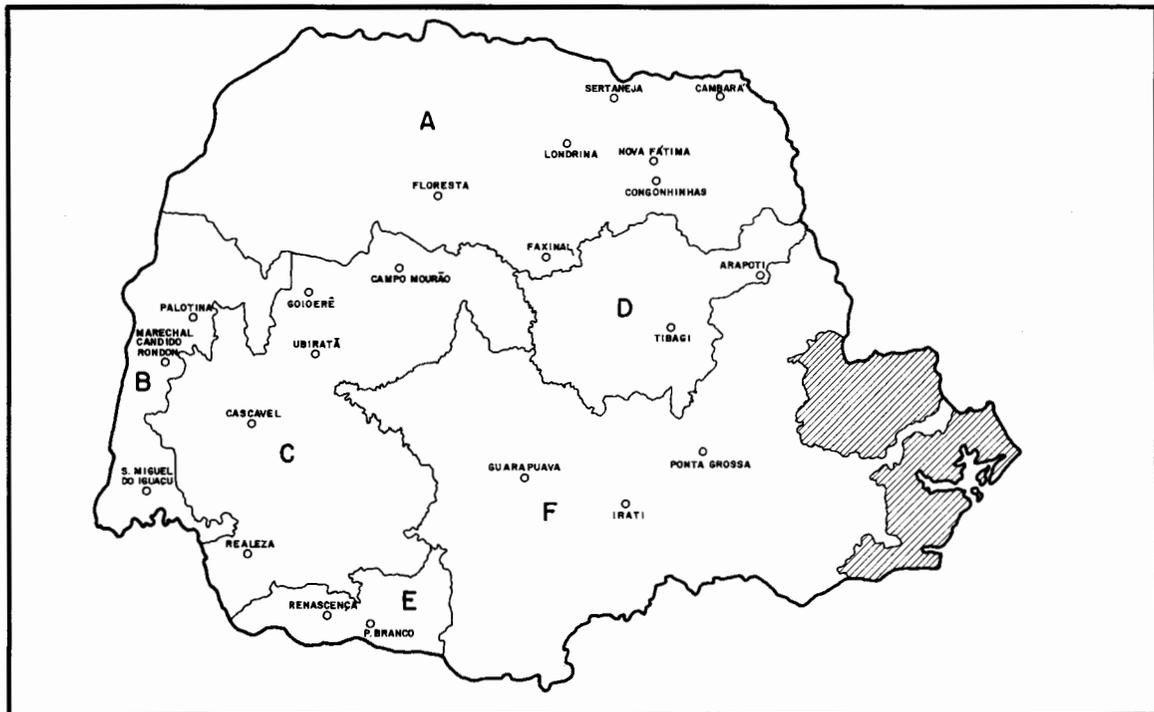


Figure 4. Cultivar recommendation zones and locations of wheat experiments.

Collaborative Work Between CIMMYT and IAPAR

Training and scientific visits

Between 1976 and 1986, nine IAPAR researchers have visited CIMMYT for scientific visits of 2 weeks to training stays of up to 8 months. Annually, CIMMYT scientists have visited and observed IAPAR breeding work in Paraná.

Germplasm exchange

Germplasm exchange between CIMMYT and IAPAR started in 1975 when CIMMYT supplied the stations at Londrina and Ponta Grossa with seed for international trials, screening nurseries, and the F₂ segregating populations of wheat, triticale, and barley.

Since 1984, 641 F₁ populations of crosses made at Londrina have been sent to CIMMYT/Mexico (Cd. Obregon) with the objective to advance one generation in the selection process. After 1987, shuttle breeding between IAPAR and CIMMYT will be intensified as the seeds of the F₃ generation originated from F₂ plants selected in acid soils with aluminum toxicity will be sent to CIMMYT for planting and selection at Cd. Obregon.

Contributions of the Mexican wheats to the Brazilian germplasm for planting in the acid soils have included:

- * Reduction in height.
- * Shorter crop cycle.
- * Stronger straw to combat lodging.
- * Resistance to leaf rust, stem rust, and powdery mildew.
- * Increase in yield potential.

In 1986, more than 60% of the lines included in the intermediate and final yield trials for acid soils in the northern and western parts of the state (and more than 90% in trials conducted in south central Paraná) originated from the crosses between Brazilian and Mexican wheats.

Outstanding crosses resulting in numerous lines selected at Londrina for tolerance to aluminum toxicity are listed below. Note the presence of Alondra (Ald"S") in many of the crosses.

Fcd//CNT 7/PF70354/3/PAT 24//Bb/Kal F11687	CNT 7/Tgn//BH 1146/3/Ald"S" F11255
PAT 19/Hork//Polo CM43675	IAS 64/Aldan"S" CM47207
PAT 72195/Mus//Trm CM43689	PF70402/Ald"S"//PAT72160/Ald"S" B19789
PAT 24/Ald"S" F10263	IAS 20/H567.71//IAS 58 CMH78390
IAC 17/Ald"S" F10320	BH 1146/Ald"S" IP5335
Ald"S"/Lagoa Vermelha IP5342	CNT 10/Ald"S" IP5339
	IAS 58/4/Kal/Bb//Cj"S"/3/Ald"S" CM50404

Among the segregating populations grown at Ponta Grossa in 1985, some outstanding crosses, considering the number of plants or lines selected, are listed below:

- * Trigo BR 5/Polo 8229/3/PF 72640/PF 7326//PF 7065/Ald"S"
- * IAS 20/TK66//Unfuli/Ald"S"/3/CEP 7780
- * Ald"S"/CEP 75289//Ald"S"/3/BH 1146/CEP 7780
- * Pel 72380/Atr 71//PAT 24/Ald"S"/3/IAC 5/PAT 7219
- * Pel 72380/Atr 71//Pel 72357/4/PAT 7392/3/Ald"S"/4/BH 1146
- * PF 7339/Thb"S"
- * CEP 7779//Mrs/COC
- * CEP 7780/Thb"S"
- * Trigo BR 1/Cal//Kvz/3/Torin 73/4/Trigo BR 1/Pamir
- * Tifton/OC 8124//IAC 5/Aldan

Problems that yet remain to be solved for new cultivars being developed through the fruitful germplasm exchange with CIMMYT include:

- * Susceptibility to head sprouting.
- * Susceptibility to leaf and spike diseases caused mainly by *Helminthosporium* spp. and *Septoria* spp.
- * Susceptibility to Gibberella.
- * Susceptibility to grain shattering.

Recommended cultivars for Paraná's various wheat zones (see Figure 4) originating from crosses between Brazilian and Mexican germplasm are listed below.

CEP 13-Guaiba
PAT 19/Ald"S"//Gaboto/Lagoa Vermelha
Zones D, E, F

IAPAR 18-Marumbi
PF 72640/PF73261//PF 7065/Ald"S"
Zones A, B, C, E

IAPAR 22-Guarauna
CNT 8/Ald"S"
Zones D, E, F

OCEPAR 8-Macuco
IAS 64/Aldan"S"
Zones A, B, C, E

OCEPAR 9-Perdiz
IAS 58/Bjy"S"/5/Mo 73/4/Mplm/Cno/7C/3/Cc
Zones B,C

OCEPAR 10-Garca
IAC 5/Aldan"S"
Zones D, E, F

OCEPAR 11-Juriti
IAC 5/Aldan"S"
Zones A, B, C, D, E

OCEPAR 13-Acaua
Mrng/3/IAS 20/Pato(B)//Bb/INIA
Zones A, B, C, F

Trigo BR 14
IAS 63/Ald"S"//Gaboto/Lagoa Vermelha
Zones D, E, F

Trigo BR 21
Cajeme E71/PF 70553
Zones A, D



Sanjaya Rajaram, head of the CIMMYT Bread Wheat Program (center) consults with Brazilian cooperators in the field plots at Cd. Obregon, Sonora, Mexico. From left: Ottoni de Sousa Rosa, CNPT/EMBRAPA; Ricardo Matzenbacher, CEP/FECOTRIGO; Manuel Bassoi, OCEPAR; and Luiz Campos, IAPAR.



Man Mohan Kohli, CIMMYT breeder assigned to the Southern Cone of South America (left), and João Carlos Felicio, IAC wheat breeder, inspect material at Campinas, São Paulo.



IAPAR's wheat breeding team (from left) Carlos Riede, Luiz Campos, and Y.R. Mehta in the IAPAR plots at Londrina, Paraná, Brazil.



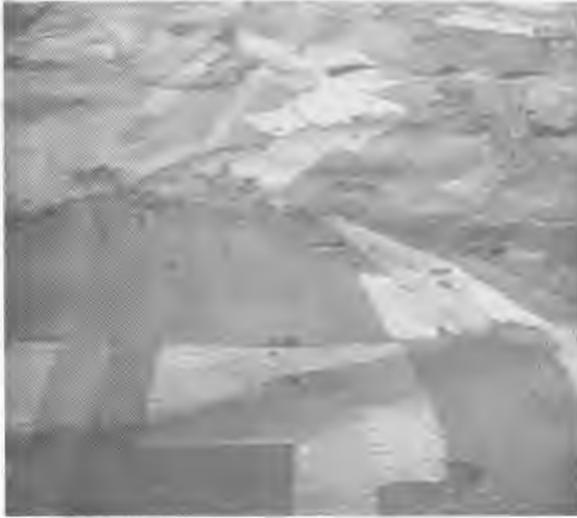
At Cd. Obregon, Sonora, Manoel Bassoi of OCEPAR prepares seed of selected lines for shipment back to Paraná.



Tolerance and susceptibility of wheat to Rio Grande do Sul's acid soils are easily determined. Compare the root growth of aluminum-tolerant IAC 5-Maringá (left) to that of aluminum-susceptible Anahuac 75.



Technician Jaime Lopez-Cesati washes wheat seedling roots as part of the screening procedures in CIMMYT's aluminum laboratory.



Paraná has become Brazil's leading wheat-producing state. At left, an aerial shot of an ocean of wheat in the Tibaji River Valley of Paraná. Below, harvest underway near Londrina, and lime awaiting application in an acid soil area.



WHEAT BREEDING AT THE CAMPINAS AGRONOMIC INSTITUTE

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Introduction

Wheat cultivation in the State of São Paulo, was initiated in 1556 (7) when the crop was introduced in the then Province of São Vicente. Later, it shifted to the Piratininga area, where the first grinding mills were operated. However, stem rust (*Puccinia graminis* f.sp. *tritici*) soon appeared and meaningful wheat cultivation in Brazil shifted to the southern part of the country.

Through the years, wheat production in São Paulo has had a cyclic expansion and reduction in cultivated area mainly due to production instability caused by imported varieties (2). These varieties, susceptible to the existing stem rust races in the state, as well as to races originating in other countries with different climatic conditions, never showed any promise. Many times, these wheats, when distributed to farmers, never reached heading, because of their vernalization requirements.

The first positive results with imported germplasm were realized with a group of varieties from Pusa, India--Pusa 4, Pusa 6, and Pusa 12, which had certain adaptation in São Paulo. However, Alcover (2) reported that stem rust epidemics made it impossible to cultivate these varieties commercially.

In 1945, Iwar Beckman distributed a variety called Frontana from the Estação Experimental Fitotecnia da Fronteira at Bage. This variety, derived from a cross between Fronteira and Mentana (2), was widely cultivated in São Paulo because of its excellent agronomic qualities, tolerance to acid soils, and resistance to race 15 of stem rust. However, it was eventually discarded due to its high susceptibility to stem rust races 11 and 17.

BH 1146, developed by Ildefonso Correia through the cross PG 1//Fronteira/Mentana at the Instituto Agronomico de Belo Horizonte, was recommended to the farmers in 1955; it is still cultivated today in São Paulo, even though it is susceptible to existing stem rust races. It is tolerant to soil acidity, early-maturing, and drought-tolerant.

Mendes (10) concluded that one of the principle ways to intensify wheat production in Brazil would be to create appropriate varieties for each region. The work conducted by the IAC resulted in the released of cultivars with the abbreviation IAC (IAC 1 to IAC 11) between the end of the 1960s and the beginning the 1970s. Of these cultivars, IAC 5 became an important variety in Brazil and was the most popular wheat in many different wheat growing regions in the late 1970s and early 1980s (1, 2, 3). In recent years, the planting of IAC 5 has declined, mainly because of the appearance of new cultivars that have higher yield potential and resistance to diseases.

Breeding work in the 1970s resulted in the cultivation of varieties of Mexican origin in highly fertile soils without Al⁺⁺⁺ toxicity. These varieties have short height and resistance to stem rust and leaf rust (3, 4, 8). Mexican cultivars Tobari 66, Inia 66, Jupateco 73, and Alondra S-43 were recommended to the farmers. Presently, the Mexican cultivar, Anahuac F75, represents the largest irrigated and nonirrigated areas planted in São Paulo in soil where Al⁺⁺⁺ is not a problem.

New wheat cultivars were brought São Paulo in the late 1970s and early 1980s as a result of the joint efforts of different research institutes. Cultivars IAC 13 (CIANO 67/IAS 51), IAC 17 (Iassul/Irn 526.63), and IAC 18 (BH 1146*4/S 12) have been recommended based on yield trials conducted in different wheat growing regions of São Paulo, in soils with and without aluminum (9, 12).

Objectives

For the State of São Paulo, breeders working to develop new cultivars with good agronomic characters consider the following aspects:

- * Good tillering, higher number of spikes per plant, large and dense spikes, large grains and with good test weight, spikelets with a large number of fertile flowers, and short cycles (100-120 days) to allow crop rotation. Early maturing wheats are less exposed to adverse climatic conditions. Other desirable characteristics include dwarf stature, mainly for the irrigated areas; resistance to shattering, lodging, cold, and drought.
- * For the state of São Paulo, the varieties, should have resistance to stem rust and leaf rust. Besides specific resistance, it is important to introduce nonspecific resistance to these diseases in new cultivars. Also resistance to septoria and *Helminthosporium* and to insect pests such as caterpillars and aphids is needed.
- * Tolerance to Al, Mn, and Fe toxicities and phosphorus uptake efficiency.
- * Better nutritional and industrial quality.
- * An efficient seed multiplication program to increase the supply accelerate the distribution to farmers of new cultivars.

Methodology

Germplasm collection

IAC maintains approximately 3000 introductions, the most promising which have desirable qualities such as resistance to predominant races of stem rust and leaf rust, tolerance to aluminium toxicity, resistance to lodging, short cycle and dwarf stature (80 to 100 cm), and high-yield potential. These lines are used for crossing with commercial cultivars to obtain hybrids in the F₁ generation.

Four CIMMYT nurseries are planted annually at the experiment station of Capão Bonito: 1) Leaf rust-resistant material, 2) the Aluminum Screening Nursery, 3) the Helminthosporium Screening Nursery, and 4) the Aluminum Tolerance and Disease Resistance Screening Nursery. Six nurseries are also planted annually at the Campinas Experimental Center: 1) International Bread Wheat Screening Nursery, 2) Heat Tolerance Screening Nursery, 3) Advanced Lines from Southern Cone of South America, 4) Collection A of Wheat Cultivars from EMBRAPA, 5) Collection B of Wheat Cultivars from EMBRAPA, and 6) a collection from CPAC-EMBRAPA. Observations are made on every line regarding the vegetative cycle, average plant height, disease rating, lodging, and yield. The lines selected from the ten nurseries are used in the crossing block. These lines are also included in the preliminary yield trials planted annually in the wheat growing regions of São Paulo.

Crossing block

The crossing block consists of 300 varieties and lines planted in the net house at two sowing dates, along with some F_1 populations from the previous year. The F_2 populations from CIMMYT are tested in IAC's aluminum laboratory for tolerance to Al^{+++} tolerance.

About 2400 plastic pots (0.3 m in height and 0.2 m in diameter) are used. Two planting dates permit the crossings of cultivars, lines, and hybrids of different vegetative cycles. On an average, 1000 crosses are made annually.

Planting of F_1 generation

The material is planted at IAC's Campinas station in 0.5-m rows spaced at 0.4. From each line, individual spikes are selected at maturity. Selected spikes are divided into three lots to form three selection blocks which are planted the following year at the Experimental Station at Capão Bonito (acid soil), Monte Alegre do Sul (corrected soil and sprinkle irrigated), and in a farmers' fields in the Paranapanema Valley region (soil with high fertility).

Selection of segregating F_2 - F_9 populations

These selections are made in different wheat growing areas of São Paulo, under irrigated or nonirrigated conditions. The F_2 populations of IAC and CIMMYT are laboratory tested in nutrient solutions for tolerance to Al^{+++} in nutritive solutions (6). Plants showing Al -tolerance in the solution of 6 mg/liter of Al^{+++} are selected and transplanted in plastic plots containing corrected and fertilized soil and placed in the net-house. In each pot, four plants are maintained and identified individually. Each population is represented by a maximum of 10 pots. At maturity, selection of spikes are made considering plant height, vegetative cycle, yield potential, and disease resistance. Seeds from selected spikes are planted in the southern region and the Paranapanema Valley for further selections.

Annually, seeds from 120,000 spikes obtained from the F_2 - F_9 segregating populations are planted at experiment station fields at Campinas, Tiete, Capão Bonito, Itarate, Tatui, Monte Alegre do Sul, and in the farmers' fields at Cruzalia, Maracai, Paraguacu Paulista, and Florinea. One line of 1 m per spike is planted with a spacing of 0.20 m between the lines. One check cultivar is planted after every 50 lines. At maturity, individual spikes are selected and replanted the following year for further selections. Uniform lines within the F_5 to F_9 populations are also selected and tested in following year in the preliminary trials of progenies.

CIMMYT trials

The International Spring Wheat Yield Nursery, consisting of 50 lines, is planted annually in three replications at the experimental station at Campinas. Each plot is composed of six rows of 3 m each with a row spacing of 0.20 m. Observations are made during the period between emergence and maturity for plant height, lodging, and resistance to stem rust, leaf rust, and powdery mildew. Plots are harvested separately and yields are recorded. Promising lines are tested the following year in the trials of new varieties.

Preliminary trial of progenies

The objective of this trial is to test the uniform and good quality lines obtained from the F₅ to F₉ populations of IAC and other national and international institutions. At this stage, very little seed of the progenies is available. Considering the large number of progenies to be tested, the trials are planted at eight locations: Experimental Station of Capão Bonito (1000 lines), Santa Ines farm at Maracai (1000 lines), Santa Lucia farm at Cruzalia (1000 lines), Experimental Station of Tatui (1400 lines), Experimental Station of Tiete (1000 lines), Experimental Station of Monte Alegre do Sul (1000 lines), Experimental Station of Itarare (1335 lines), and Experimental Station of Campinas (1400 lines).

In these trials, each progeny is planted in 3-m row with a row spacing of 0.40 m to facilitate observations and to minimize the competition between tall selections and the short and medium ones. After every 100 lines, susceptible spreader checks for stem rust and leaf rust are planted, such as Alondra 4546, BH 1146, IAC 13, IAC 17, IAC 18, Irn 526.63, IAC 24, Anahuac, and IAC 36.

At the initial stage of maturity, observations are made on days to maturity, plant height, disease resistance, and lodging. Promising lines are harvested and yields are recorded.

Trials of new lines

The objective of these trials is to test, on a regional basis, the promising material obtained from the preliminary progeny trials, along with the recommended cultivars, so that the best lines can be promoted and further tested in the preliminary yield trials.

At this stage, the breeding program still depends on limited seed material which means only one to three rows of 3 m each. Because of the large number of lines to be tested, the trials are planted (100 lines each) at six locations: Experimental Station of Capão Bonito, Santo Antonio farm at Colombia with sprinkle irrigation, Santa Ines farm at Maracai, Santa Lucia farm at Cruzalia, and Experimental Stations of Tatui and Monte Alegre do Sul with sprinkle irrigation.

In these trials, five rows of 3.0 x 0.20 m are planted for each line. Check varieties included are: Alondra S-46, BH 1146 IAC 5, IAC 13, IAC 17, IAC 18, Irn 526.63, Londrina, Paraguay 281, PAT 24, IAC 24, and Anahuac 75.

At the initial stage of maturity, observations are made on days to maturity, plant height, disease resistance, and lodging. Promising lines are harvested at each location and yields are recorded.

Preliminary yield trials

The objective of these trials is to test, on a regional basis, materials originating from the trials of new lines, along with the recommended cultivars, so that the best ones can be tested further in the trials of new varieties.

At this stage of the breeding cycle, there is a relatively smaller number of lines to be tested compared to the earlier trials; seed quantity is over 2 kg per line. Thus, it is possible to have plots with three replications at each location.

The preliminary yield trial is planted at seven locations: Experimental Stations of Capão Bonito at Tatui, Itarare, and Tiete and Campinas; Santa Cruz farm at Maracai; and Santa Lucia farm at Cruzalia.

Each trial consists of 70 varieties and 5 commercial cultivars as checks, and is planted in three replications. Each plot is composed of 5 rows of 3.0 x 0.20 m.

At the initial stage of maturity, observations are made on days to maturity, plant height, disease resistance, and lodging. Promising lines are harvested at each location and yields are recorded. The best varieties are further tested in the following year in the trials of new varieties.

Trials of new varieties

The objectives of these trials is to test, on a regional basis, the germplasm selected during different stages of the breeding program, so that the materials with high potential can be further included in the intermediate yield trials and later recommended to the farmers.

The genetic material included in the trials of new varieties represents new wheat germplasm obtained by the breeding program through the process of selection in the segregating populations or in the lines introduced from other national and international research centers.

At this stage of the breeding program, enough seed quantities are available for experimentation as well as for small multiplication for future needs. Forty trials of new varieties are conducted every year, and each trial is planted at three locations. The experimental design used in these trials is randomized blocks with 25 varieties in three replications at each location. Each plot is composed of five rows of 3.0 x 0.20 m. At the initial stage of maturity, the same observations are made as mentioned in earlier trials.

Table 1 shows the average yields of six varieties obtained in the trials of new varieties under dryland conditions in 1984 and 1985. The variety IAC 226 yielded 18, 54, and 69% better than the cultivars BH 1146, Alondra S 45, and Anahuac 75, respectively.

Data on the average yields of varieties included in the trials of new varieties conducted at the experimental station of Monte Alegre do Sul, under sprinkle irrigation are presented in Table 2. The cultivar IAC 215 yielded 7141 kg/ha, which is considered to be the highest yield so far obtained under experimental conditions in the state of São Paulo. This germplasm, originating from CIMMYT-Mexico, yielded 32% and 19% better than the commercial cultivars IAC 24 and Anahuac 75, respectively.

Intermediate yield trials

The objective of these trials is to test the materials derived during the earlier breeding cycles, along with the recommended cultivars, under both irrigated and sprinkle-irrigated conditions. The outstanding varieties from these trials are further evaluated in the "Ensaio Centro Sul Brasileiro de Pesquisa de Trigo" yield trials.

The experimental design is randomized blocks with 25 treatments and four replications. Each plot is 5 rows of 5.0 m, 0.2 m apart ; spacing between plots is 0.60 m. A seed density of 350-400/m² is used.

Five intermediate yield trials are conducted every year in acid soils with aluminium toxicity at Pedrinhas Paulista, Maracai, Palmital, Capão Bonito, and Itarare. Seven other intermediate yield trials are conducted in corrected soils at Pedrinhas Paulista, Maracai, São Jose das Laranjeiras, Aguai, Mococa, Colombia, and Guaira. At the initial stage of maturity, the same kind of observations are made as mentioned earlier.

Table 1. Average yield of six wheat varieties planted under dryland conditions in 1984 and 1985.

Variety	Yield (kg/ha)
Alondra 1/IAC 5 = IAC 225	2444
Alondra 1/IAC 5 = IAC 226	2643
CNT 9/BH 1146 = IAC 227	2329
BH 1146	2228
Alondra 4546	1716
Anahuac 75	1567

Table 2. Average yield of six varieties planted at Monte Alegre under irrigated conditions in 1985.

Variety	Yield (kg/ha)
Jup/Emu"S"//Gjo"S" = IAC 215	7141
Jup/Emu"S"//Gjo"S" = IAC 216	6615
PVN"S" = IAC 217	6522
H567.71/PAR(3) = IAC 218	5667
IAC 24	5408
Anahuac 75	6024

Official trials of the Comissao Centro Sul Brasileira de Trigo

The objective of these trials is to test new cultivars annually in comparison with the commercial cultivars, so that the best ones with wider adaptability can be recommended to São Paulo farmers.

The experimental design is randomized blocks with four replications at each location. The plots are composed of 5 rows of 5.0 m, 0.20 m apart; spacing between plots is 0.20 m. Seeding density is 350-400/m².

Yield trials for soils without acidity (Ensaio Centro Sul Brasileiro de cultivares de trigo para solos sem acidez)--These trials are conducted at Pedrinhas Paulista, Palmital, Maracai, São Jose das Laranjeiras, under irrigated conditions, and at Aguai, Campinas, Guaira and Colombia under sprinkle-irrigated conditions.

Yield trials for acid soils--These trials are conducted at Pedrinhas Paulista, São Jose das Laranjeiras, Maracai, Palmital, Capão Bonito, Itarare, and Paranapanema under dryland conditions.

Yield trials for the cultivars commonly grown in São Paulo (Ensaio de cultivares em cultivo no estado de São Paulo)--These trials are conducted at Pedrinhas Paulista, Palmital, Maracai, Cruzalia, São Jose das Laranjeiras, Itarare, Capão Bonito, and Paranapanema, under dryland conditions. Table 3 shows the average yield of the commercially-grown cultivars tested in 1985 at five dryland locations in the Paranapanema Valley.

Special regional irrigated yield trials (Ensaio regional especial irrigado de cultivares)--These trials are conducted at Colombia, Guaira, Campinas, Aguai Mococa, and Tatui.

Table 3. Average yield of 11 varieties planted in five dryland locations of Paranapanema in 1985.

Variety	Yield (kg/ha)
Alondra 4546	1922
Anahuac	2062
BH 1146	2319
IAC 5	2296
IAC 17	2222
IAC 18	2149
IAC 21	2420
IAC 23	1926
IAC 24	2167
Paraguay 281	2126
PAT 72247	2054

Evaluation of recommended cultivars for tolerance to Al⁺⁺⁺

The objectives of these trials are twofold:

* To identify aluminum-tolerant cultivars in acid soils with abundant soluble or exchangeable aluminum. The most tolerant cultivars are also used in the breeding program as sources of tolerance to aluminum toxicity.

* To make possible adequate distribution of Al⁺⁺⁺ tolerant and susceptible cultivars to the Central South Brazilian trials conducted in soils with and without Al⁺⁺⁺ for further testing.

Table 4 shows the average root length of 21 commercial wheat cultivars grown in São Paulo. The root length was measured after the plants were grown in a nutrient solution for 72 hours followed by 48 hours in solutions with six different aluminum concentrations (0, 2, 4, 6, 8, and 10 mg/liter). This methodology is described in the literature by several authors (5, 6, 11).

Table 4. Average root length (mm) of 21 commercial wheat cultivars grown in São Paulo measured after the plants were grown in a nutrient solution for 72 hours followed by 48 hours in solutions with six different aluminum concentrations.

Variety	Al ⁺⁺⁺ concentrations in solution (mg/l)						Reaction
	0	2	4	6	8	10	
BH 1146	95.1	62.6	48.0	40.3	32.6	26.6	T
CNT 8	64.5	19.9	00.0	00.0	00.0	00.0	S
IAC 18	84.0	57.3	44.1	36.6	21.5	16.9	T
IAC 28	69.1	39.2	36.4	31.3	23.1	16.6	T
IAC 5	52.2	30.8	22.5	23.0	06.5	02.5	T
IAC 74	82.4	56.4	40.3	27.6	04.3	03.6	T
IAC 13	58.9	37.5	26.5	12.0	03.6	06.7	T
IAC 17	66.5	46.2	29.1	11.5	00.0	00.0	M
Alondra "S" 46	50.7	21.0	00.0	00.0	00.0	00.0	S
IAC 162	65.5	31.3	04.7	00.0	00.0	00.0	S
Anahuac 75	62.3	00.0	00.0	00.0	00.0	00.0	MS
Paraguay 281	51.1	12.1	00.0	00.0	00.0	00.0	S
PAT 72247	75.2	44.1	27.1	26.4	09.1	04.2	T
IAC 22	54.2	29.5	23.9	12.8	02.3	02.9	T
IAC 161	63.4	41.0	18.7	09.5	00.0	00.0	M
Mitacore	64.1	35.6	25.0	07.2	00.2	00.0	M
IAC 23	56.9	26.6	12.8	00.0	00.0	00.0	S
BR 2	60.6	33.7	29.2	12.3	03.5	02.5	T
IAC 21	42.6	24.9	27.4	19.2	09.9	03.8	T
CEP 7780	68.4	46.7	14.0	04.5	00.0	00.0	M
IAC 24	50.8	34.4	34.5	29.2	14.1	03.7	T

T= Resistant; M= Moderate; S= Susceptible; MS= Very Susceptible

New Cultivars

Following are the cultivars obtained by IAC and recommended to farmers since 1980.

IAC 21-Iguaçu

A cultivar originated from the cross Siete Cerros/C 17) made in 1971. Siete Cerros is originated from a Mexican cross Penjamo 62/Gabo 55; C 17 (Lagoa Vermelha) originated from Rio Grande do Sul cross (Veranopolis*2//Marroqui/Newthatch).

Characteristics--Height is between 90-110 cm; days to maturity equals 120 days; auricle light green; leaf position intermediate; cream-color panicles, 10.2 cm in length and with fusiform awns; up to 22 spikelets per spike, averaging 37 cream-colored grains per spike. The spikes average 6.11 mm in length, 3.176 mm in width, and 2.45 mm of thickness. This cultivar is recommended for acidic soils and subsoils with low fertility, since it possesses tolerance for these conditions. However, it can also be sown in more fertile soils, but with limited fertilizers to avoid lodging. The cultivar has moderate resistance to stem rust and *Helminthosporium*, but is moderately susceptible to leaf rust and powdery mildew.

IAC 22-Araguaia

Originated from a cross (Pel 21414.66/IAC 5) made in 1971. The cultivar Pel 21414.66 was introduced from Instituto de Pesquisa Agropecuaria do Sul (IPEAS), Pelotas, R.S. IAC 5-Maringá originated from a the cross Frontana/Kenya 58//Ponta Grossa 1 at the Experimental Station of Capão Bonito.

Characteristics--Height is between 100-115 cm; short cycle of 120 days to maturity; auricle light-green; leaf position intermediate; cream-color panicles of 10.8 cm with fusiform awns; 23 spikelets per spike, average 42 cream-colored grains per spike. Grain dimensions are: 6.38 mm in length, 3.13 mm in width, and 2.44 mm in thickness. This cultivar is recommended for soils and subsoils with moderate acidity and a medium- to high-level of fertility.

High doses of nitrogen fertilizers should be avoided because this tall cultivar tends to lodge, especially in highly fertile soils. The cultivar is resistant to stem rust, moderately resistant to *Helminthosporium*, and susceptible to leaf rust and powdery mildew.

IAC 24-Tucurui

Originated from the cross IAS 51/4/Son 64/Y50E//Gto/3/2*Cno.

Characteristics--Medium height of 80 cm; short cycle of 120 days to maturity, violate-colored auricles, but not over all entire area; leaf position intermediate; cream-colored spikes with oblong awns averaging 8.39 cm in length; average 17 spikelets per panicle; average 44.4 redish-brown grains per spike. The grain dimensions are 5.91 mm in length, 3.05 mm in width, and 2.47 mm in thickness. It is recommended for acidic soils and subsoils with low fertility. It can also be grown in fertile soils without any nitrogen application restrictions, mainly for the irrigated areas. This short-cycle cultivar is resistant to lodging, resistant to stem rust, moderately resistant to powdery mildew, but susceptible to leaf rust and highly susceptible to *Helminthosporium*.

IAC 74-Guapore

IAC 74 originated from the cross Sonora 63*2/C 17. Sonora 63 is originated from the CIMMYT cross Yt 54/N10B//2*Yt 54. C 17 originated from the cross Veranopolis*2//Marroqui/Newthatch made in the Rio Grande do Sul.

Characteristics--Height between 90-110 cm; short cycle of 120 days to maturity; auricle is light yellowish-green; leaf position intermediate; fusiform panicles light brownish-yellow with awns 9.8 cm long; 21 spikelets per panicle; average 36.6 grains per spike. The grains are yellowish-brown.

IAC 28

IAC 28 originated from the cross Lerma Roja 64/BH 1146//Sonora 63. Lerma Roja 64 and Sonora 63 were originated from CIMMYT, Mexico; BH 1146 originated from the Instituto Agronomico de Belo Horizonte, MG.

Characteristics--Plant height between 90 and 100 cm; short cycle of 120 days to maturity; intermediate vegetative habit; violet auricles, intermediate positioned green leaves; panicles are cream colored, elliptical, and with awns 9.2 cm in length; 25 spikelets per panicle; and 38 cream-colored grains per spike. The spikes are cream colored and 5.95 cm in length. Recommended for acidic soils and subsoils of medium fertility. IAC 28 can also be grown in more fertile soils, but with limited nitrogen fertilizer to avoid lodging. The cultivar is resistant to stem rust, moderately resistant to powdery mildew and *Helminthosporium*, but susceptible to leaf rust and *Gibberella*.

IAC 161-Taiama

IAC 161 was selected at IAC and originated from the Mexican cross Kavkas/Gavilan//Tito"S". It was tested in the northern region of São Paulo under sprinkle-irrigated conditions.

Characteristics--Plant height between 70 and 80 cm; medium cycle of 130 days to maturity; erect; auricle light yellowish-green; leaves intermediately positioned with ashgreen color; panicles awnless or with only apical awns, cream colored, claviform, and 9.9 cm in length; 22 spikelets per spike; average of 38 cream-colored grains per spike; grains measure 6.31 mm in length. The cultivar is recommended for moderately acidic soils and subsoils. It can also be grown in more fertile soils with nitrogen fertilizer as a topdressing, since it is very resistance to lodging. It is resistant to stem rust, leaf rust, and powdery mildew, but susceptible to *Helminthosporium* and *Gibberella*.

IAC 162-Tuiuiu

IAC 162 was selected by IAC and originated from the CIMMYT cross Kavkas//Ciano 67/Penjamó 62.

Characteristics--Plant height between 70 and 80 cm; short cycle of 120 days to maturity; erect; auricle light yellowish green; dark green leaves intermediately positioned; panicles cream color with awns and clavate; spikes 10.2 cm long with 25 spikelets; average number of grains 40.6 per spike; brownish grains 6.09 mm in length. The cultivar is recommended for nonacid soils and subsoils with good fertility. It can also be grown in soils with sprinkle irrigation and with nitrogen topdressing it is resistant to lodging. It is resistant to stem rust and leaf rust, but susceptible to *Helminthosporium*, powdery mildew, and *Gibberella*.

Conclusions

Although the wheat breeding progress in Sao Paulo has been notable, there is still great demand for new and high yielding cultivars with stable resistance to diseases and adaptation to acid soils. One important aspect is to develop varieties with high yield potential and efficient in phosphorus and nitrogen absorption, so that they can be cultivated under sprinkle-irrigated conditions.

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DEVELOPING BREAD WHEATS FOR ACID SOILS THROUGH SHUTTLE BREEDING

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Shuttle Breeding--What Is It?

Shuttle breeding in Mexico

This driving force of CIMMYT's wheat improvement programs is a well known success story. In this scheme, the segregating populations are alternately grown and selected in different locations. Successive generations are alternated (shuttled) between the two locations. The underlying philosophy is to incorporate adaptation, yield potential, and resistance to diseases and stresses encountered in two distinct locations.

In the late 1940s, Norman E. Borlaug began crossing, screening, and selecting germplasm during winter and summer cycles each year at two diverse locations, Cd. Obregón and Toluca, Mexico. A breeding cycle still takes place at the Mexican government's Northwestern Agricultural Research Station (CIANO) during the winter (November to May). This location is an irrigated desert environment near Cd. Obregon in the state of Sonora at 27.2° N latitude, 39 m elevation. Seed harvested at CIANO is "shuttled" for May and June planting at the beginning of the summer cycle at CIMMYT's research station in the central highlands near Toluca (elevation 2640 m and 19° N latitude) and at El Batan (elevation 2240 m and 19° N latitude).

At Cd. Obregon, breeding materials are crossed and resulting progenies are evaluated for their yield potential under high fertility and well watered conditions. Progeny are also screened for resistance to leaf and stem rusts.

At Toluca, breeding materials are also crossed and the germplasm is screened for resistance to stem, leaf, and stripe rusts as well as to septoria tritici blotch, septoria nodorum blotch, fusarium head scab, bacteria such as *Xanthomonas campestris* pv. *translucens*, and barley yellow dwarf virus (BYDV).

One generation a year at each of these locations enables the breeders to eliminate daylength-sensitive germplasm. Only materials that are insensitive to the daylength variation are selected.

In addition to Cd. Obregon, Toluca, and El Batan, CIMMYT uses a number of "on-station" sites in Mexico to screen for resistance to septoria tritici blotch, septoria nodorum blotch, fusarium head scab, helminthosporium leaf blotch, stripe rust, and stem rust and tolerance to heat and drought.

The use of contrasting locations for generation advancement and selection of germplasm in Mexico has resulted in many widely adapted bread wheat cultivars with high genetic yield potential. Broadly adapted cultivars such as Siete Cerros, Anza, Nacozari 76, Pavon 76, and the Veery sibs were produced in this fashion and have been released in many countries.

International shuttle breeding

Shuttle breeding has proven to be very effective in Mexico and can also work well on an international basis. The best example is CIMMYT's 14-year collaboration with Brazilian scientists. The goal in this project has been to develop high-yielding wheat cultivars with tolerance to aluminum/acid soil conditions. With shuttle breeding, dramatic results have been derived through the combination of the early work of Brazilian organizations (which developed aluminum-tolerant wheat cultivars) and the work of CIMMYT (which developed high-yielding cultivars with better agronomic type).

A number of high-yielding, aluminum-tolerant wheat cultivars have been released or recommended for release in several Brazilian states, and promising cultivars have been developed for other countries with soil aluminum problems. This article discusses some historical background, what has been accomplished, and plans for the future regarding the development of bread wheats for the problems associated with soils that have toxic levels of aluminum.

The Acid Soil Problem

Soil acidity is a major growth limiting factor for plants in many parts of the world. Approximately 1 billion hectares in the tropics and subtropics are acidic (5). This includes large areas of Brazil, the Andes of South America, China, Southeast Asia, the Himalayas of the Indian Subcontinent, and Central Africa. Currently, many of these areas are either undeveloped for agriculture, or, where cultivated, are of very low productivity. To meet the rapidly growing demand for food for the next century, these problem soils must be developed and productivity on them improved. This can be done by a combination of plant improvement, corrective chemical amelioration and fertilization, and improved management practices.

Growth limiting factors that have been associated with the acid soil complex include toxicities of aluminum and manganese and deficiencies of calcium, magnesium--and especially phosphorus and molybdenum. These acid soil factors may act somewhat independently, or more often together, to negatively affect plant growth.

Aluminum and manganese toxicities are the two most important factors limiting the growth of crop plants in many acid soils of the world. Aluminum toxicity is particularly severe below pH 5.5. Agronomists' current approach to this problem is to change the pH by adding lime to the soil. This is not always economically or physically feasible, particularly in strongly acidic subsoils.

Current Situation in Brazil

Even though Brazil is currently producing significant amounts of wheat (about 70% of the 8.6 million tons it consumed in 1987), wheat production in the country still has many problems. About 70% of the 3.4 million ha under wheat cultivation in Brazil have a low pH (between 4.0 and 5.5), high levels of aluminum and manganese, and low levels of available phosphorus, potassium, and other micro-elements. Some areas of Paraná and São Paulo states have been cleared of forest only during the past 20 years or so and

have many problems, including acidity with its associated toxicities, infertility, and shallowness of soil that is highly subject to erosion from heavy rainfall.

Average Brazilian wheat productivity has fluctuated between 300 and 1800 kg/ha between 1963 and 1987. High regional incidence of fungal, viral, and bacterial diseases; drought; and frosts are generally responsible for the dips in productivity. It is important to note that many millions of additional hectares in the Cerrados area which are otherwise suitable for wheat production also have many of the problems listed above (4).

The situation in Brazil exemplifies some of the problems of moving wheat production into the warmer nontraditional areas, an objective of a number of national programs cooperating with the CIMMYT Wheat Program. A long-term and continuous research effort will be necessary to develop crop production methodologies to stabilize production. Development of cultivars better adapted to the acid soils will continue to be a part of the overall crop improvement programs in Brazil and CIMMYT.

Historical Background of the Brazilian Acid Soil Problem

Brazilian scientists first observed differences among wheat cultivars planted in acid soils in the 1920s, although it had not yet been determined that the acid soils themselves were causing these differences. Due to the yellowing and poor growth of the plants, the problem was given the name "crestamento", which in Portuguese means "burning" or "toasting". In 1925, crosses made between the crestamento-tolerant Alfredo Chaves cultivars and the cultivar Polyssu gave rise to new crestamento-tolerant Brazilian cultivars, such as Fronteira, Surpresa, Minuano, Jesuita, and Guarany (4).

By 1942, Brazilian scientists were able to attribute crestamento to the high acidity present in the soil. Later in the decade, they determined that it was caused by the presence of toxic levels of soil aluminum (1, 2). In 1954, it was found that tolerance to aluminum was a heritable characteristic (3). Brazilian studies showed that tolerance was a dominant effect and possibly controlled by a pair of genes. In 1980, it was found that tolerance is differentiated by two independent genes.

As the Brazilian breeding programs developed, the cultivars Preludio and Carazinho were released in 1956 and 1957. Because they average 1 t/ha and showed resistance to leaf rust and tolerance to aluminum toxicity, these cultivars became very popular with farmers. In the 1960s, cultivars such as IAS 20 showed a yield potential of up to 1.4 t/ha in soils with toxic aluminum.

The increase in soybean production starting in 1968 brought about two new practices (4). Lime was applied to enhance soybean production and as a result wheat production increased also. In addition, because of the new wheat-soybean double crop system, late-maturing wheat cultivars were abandoned and only early-maturing cultivars have been used since. Liming did not eliminate the need to maintain varietal tolerance to aluminum toxicity. Because lime usually is applied only to the plow layer (top 20 cm of

soil), susceptible cultivars planted in limed soil develop their root systems only in this superficial layer, causing inadequate nutrient uptake and vulnerability to drought stress.

Era of CIMMYT Collaboration

By the late 1960s, although Brazilian cultivars had been improved through the years, they were still low-yielding, too tall, and deficient in agronomic characteristics such as spike fertility and straw strength. In 1969, John W. Gibler, then technical director of the Rio Grande do Sul Federation of Wheat and Soybean Cooperatives (FECOTRIGO), first initiated genetic material exchange with CIMMYT. The main objective was to combine the Brazilian wheats' tolerance to toxic levels of aluminum with the high yield potential of the Mexican wheats.

By 1974 Borlaug had informally arranged a shuttle breeding program between CIMMYT's Mexican bread wheat program and FECOTRIGO's newly organized Research and Experimental Center (CEP) at Cruz Alta and the National Research Center for Wheat (CNPT) of the Brazilian Agricultural Research Enterprise (EMBRAPA) at Passo Fundo. By 1977 the shuttle program was intensified and expanded to include the Organization of Paraná State Cooperatives (OCEPAR) at Cascavel. The Paraná State Agronomic Institute Foundation (IAPAR) at Londrina, the Campinas Agronomic Institute (IAC) in São Paulo State, and the Agricultural Research Center for the Cerrados (CPAC) of EMBRAPA at Brasilia also now cooperate with CIMMYT to varying degrees. See Figure 1 for the Brazilian and Mexican locations in the shuttle breeding scheme.

The exchange of genetic material between Brazil and CIMMYT permits the introduction of thousands of lines and segregating populations for all the collaborating breeding programs. The genetic combinations of high-yielding Mexican wheats with semidwarf characteristics and Brazilian wheats with aluminum tolerance are made in Cd. Obregón, Toluca, Cascavel, Passo Fundo, and Cruz Alta (Figure 1).

Promising segregating materials identified by a laboratory screening procedure (described in the following paper on page 59) are sent to several Brazilian states to be tested in acid soils and to Toluca and Cd. Obregon in Mexico for testing in nonacid soils. In Mexico, selections are made mainly for agronomic characters and resistance to stem, leaf, and stripe rusts. In Brazil, besides selecting for aluminum tolerance, selections are also made for the local disease complex of leaf rust, stem rust, *helminthosporium* spot blotch, *septoria tritici* blotch, *septoria nodorum* blotch, fusarium head scab, barley yellow dwarf virus, and bacterial stripe. In Brazil, when plants reach the full tillering stage (late August in Passo Fundo and Cruz Alta), visual evaluations are made for "crestamento" tolerance and the results are immediately telexed to CIMMYT for use during the selection process in Toluca, Mexico.

Results in Brazil

Much of the tested material is discarded because of its susceptibility to aluminum toxicity and diseases. However, Brazilian scientists are highly enthusiastic about the gains in yield potential that have been incorporated into their aluminum-tolerant wheat germplasm.

In 1980, Alondra was released for general cultivation in primarily nonacid soils as a multiline cultivar in Paraná state. However, Alondra also often yields well in acid soils and yet is susceptible to high levels of soluble aluminum. Derived from the cross D6301/Nainari 60//Weique/3/Ciano*2/Chris (CM11683), Alondra's performance in Brazil's acid soils may be partly due to its ability to efficiently extract and utilize phosphorus when phosphorus is present in low levels. Since acid soils also tend to have low levels of available phosphorus it is important that this characteristic be incorporated into germplasm intended for such soils. Brazilian scientists have identified progeny from Alondra that have higher levels of tolerance to toxic levels of aluminum and have been using them further in crossing programs.

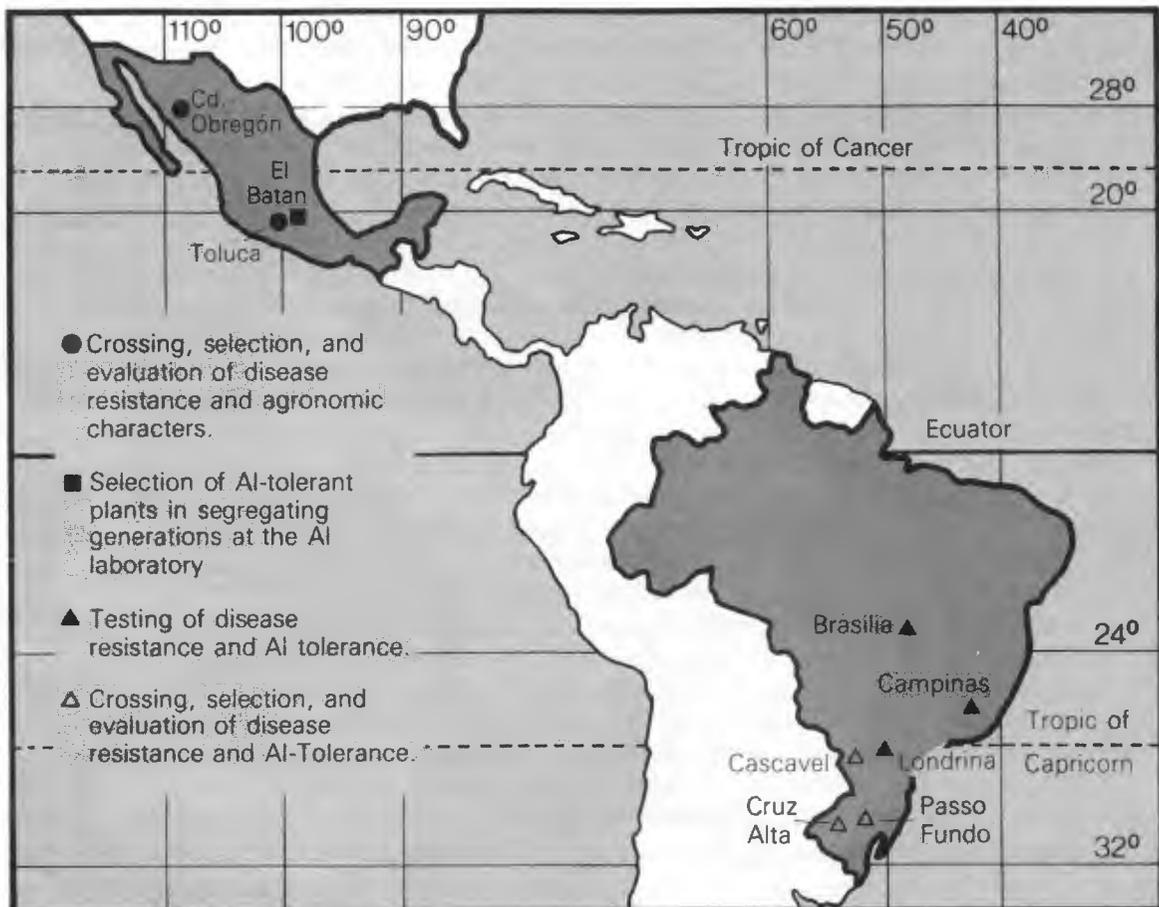


Figure 1. Mexican and Brazilian locations involved in shuttle breeding.

In recent years, a number of cultivars obtained from the shuttle breeding cooperation have been recommended for cultivation in several Brazilian states (Table 1). Alondra is in the pedigree of several of these new cultivars. In one of these cultivars, Thornbird (BR 14), increased phosphorus uptake efficiency has been combined with true tolerance to aluminum. Although Thornbird is still moderately tall, it is the first of the new generation of early, aluminum-tolerant, and high-yielding wheats emanating from this cooperative shuttle breeding effort. Thornbird and the other cultivars listed in Table 1 have increased yield potential over the current commercial Brazilian cultivars by at least 25%. In field experiments, the new high-yielding, aluminum-tolerant cultivars are producing yields higher than 4 t/ha--in some cases higher than 5 t/ha. Several advanced lines are emerging from the breeding pipeline with even higher yield potential.

In addition to high-yield potential, additional major specific traits improved in the Brazilian germplasm include:

- * Disease resistance to leaf and stem rusts and powdery mildew.
- * Better agronomic type with regard to plant type, shorter and stronger straw, and larger, more fertile spikes.
- * Better heat and drought tolerance.

Results at CIMMYT and in Mexico

CIMMYT is equally enthusiastic about the gains made by crossing Mexican wheats with Brazilian wheats and selecting under both Mexican and Brazilian conditions. These major gains in CIMMYT germplasm include:

- * Aluminum tolerance.
- * Phosphorus uptake efficiency.
- * Resistance or tolerance to the leaf spotting diseases, such as *Septoria*, *Helminthosporium*, and *Fusarium* spp.
- * Longer leaf duration (stay-green effect).

In the high-altitude regions of Mexico in the states of Michoacan and Jalisco, soils are highly leached and acidic with a high phosphorus fixation problem. In these soils, the aluminum-tolerant cultivars selected through the Mexican/Brazilian shuttle have shown a yield advantage superior to the traditional cultivars such as Anahuac 75 and Pavon 76. A cultivar recently released in Michoacan is Curinda M-87 (IAS 58/4/K1a/Bb//Cj/3/Ald"S"; CM50464-12Y-4M-1Y-1M-0Y).

Table 1. Cultivars obtained through alternate selection at Brazil and Mexico and recommended for cultivation in several Brazilian States.

Cultivar	Pedigree
CEP 13-Guaiba	PAT 19/Alondra "S"//Gaboto/Lagoa Vermelha F11860 F500-900Y-312Z-0A-0Y
MG 1	IAS 64/Aldan"S" CM47207-16M-2Y-3F-704Y-700Y
IAPAR 18-Marumbi	PF72640/PF73261//PF7065/Alondra"S"
IAPAR 22-Guarauna	CNT 8/Alondra"S"
OCEPAR 8-Macuco	IAS 64/Aldan"S" CM47207-6M-103PR-2T-0T
OCEPAR 9-Perdiz	IAS58/Bjy"S"//Bnq CM47971-A-4M-105PR-2T-0T
OCEPAR 10-Garca	IAC 5/Aldan"S" CM46961-16M-109PR-1T-0T
OCEPAR 11-Juriti	IAC 5/Aldan"S" CM46961-16M-113PR-1T-0T
OCEPAR 12 Maitaca	PF 71124/PAT 72162 B 13707-0A-0Z-0L-0M-1L-0P
OCEPAR 13-Acaua	IAC 5/3/IAS 20/PATO B//Bb/INIA B 14402-0M-1T-2T-0T
Trigo BR 14	IAS 63/Alondra"S"//Gaboto/Lagoa Vermelha Mixture of lines PF79765, PF79767, PF79780, PF78782, and PF79791 = Thornbird"S"
Trigo BR 16-Rio Verde	PF70402/Alondra"S"//Pat 72160/Alondra"S" B 19789-H-508M-1Y-10F-701Y-1F-700Y
Trigo BR 21	Cajeme E71/PF70553

Progress in Other Countries

CIMMYT assembles outstanding advanced lines emanating from this shuttle project into the Aluminum Tolerance Screening Nursery (ATSN) and is currently sending this nursery to 50 locations worldwide. Thus, outstanding lines for yield, aluminum toxicity tolerance, and agronomic type are fed back into the crossing program to further pyramid favorable genes into better cultivars.

The cooperative shuttle program and distribution of the resulting materials through the ATSN is beginning to provide benefits to other countries such as Madagascar, Zambia, Rwanda, Cameroon, and Ecuador. Shuttle breeding with these countries may commence in the near future as well.

The Future

The Cooperative shuttle program has provided tremendous benefits to the CIMMYT and Brazilian bread wheat breeding programs. CIMMYT and Brazilian scientists agree that the current cooperative effort should be continued and enlarged to place greater emphasis on some problems currently under investigation and to consider other problems as well. These problems include:

- * Bacteria (*Xanthomonas* spp., *Pseudomonas* spp., etc).
- * Fusarium head scab.
- * Barley Yellow Dwarf and other viruses, including vectors.
- * Greenbug (*Schizaphis graminim*).
- * Phosphorus uptake efficiency.
- * Sprouting.
- * Midterm drought and early heat stress.
- * Maintaining the current level of tolerance to aluminum toxicity.
- * Improving quality characteristics.

We see what has been accomplished through 1987 as Phase 1 of this cooperative program. We believe two more phases of 5 years duration each are needed to help solve the problems listed above. Phase 2 would emphasize the broadening of disease resistance. Phase 3 would emphasize increasing yield potential.

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CIMMYT'S LABORATORY METHOD FOR SCREENING WHEAT SEEDLING TOLERANCE TO ALUMINUM

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Introduction

To facilitate the breeding effort for developing wheat varieties that will do better in the acid soils of Brazil and other countries, CIMMYT continues to use a laboratory procedure to screen thousands of segregating lines for tolerance to soluble aluminum. This effort is significant because it is estimated that more than 20% of the world's potential agricultural land is adversely affected by factors associated with the acid soil complex (12). The high soluble aluminum level is a major problem in several areas of tropical and subtropical environments.

The low productivity of most crops in the acid soils of humid tropic and subtropic environments is due mainly to such soil characteristics as:

- * Low pH and high soluble aluminum, manganese, and iron concentrations.
- * Deficiency of available phosphorus and some microelements.
- * Low calcium, magnesium, potassium and sulfur concentrations (1, 9, 14).

Because of these problems, root growth of plants is reduced, resulting in a low intake of available water in the profile.

In general, aluminum toxicity is associated with low soil pHs below 5.5; it is severely increased when the pH falls below 5.0. Such low pHs increase considerably aluminum solubility in the soil where more than half of the cationic exchange sites can be taken by aluminum (6, 8). The extent to which aluminum becomes soluble in the soil and the degree to which it becomes toxic to plants depend upon a number of factors in addition to soil pH such as the types of clay present, salt and cation concentration, and the soil's buffer capacity and organic matter content (8).

According to Tisdale et al. (16), the soil acidity is associated with humus or organic matter, aluminosilicate clays, iron and aluminum oxides, interchangeable aluminum, soluble salts, and carbon dioxide. It is known that when interchangeable aluminum combines with basic cation losses, such as calcium, magnesium, and potassium, soils become acidic. Aluminum can also interfere with phosphorus metabolism by causing an accumulation of high quantities of inorganic phosphates within the roots, thereby reducing the roots' ability to absorb and transport this important element.

Management alternatives to correct acid soil problems include (1, 14):

- * Deep liming to correct acidity (can represent economic and technical problems for farmers).
- * Superficial liming (the subsoil remains acidic).
- * Genetically improving crops to increase tolerance to soluble aluminum.
- * Combining genetic improvement with better soil management practices.

Different cereal species and varieties within the same species have wide variability in their tolerances to high aluminum levels in acid soils. For example, there is great genetic diversity in hexaploid wheat (4, 7, 10, 11, 13, 15). However, little is known about the mechanism involved in plant tolerance to aluminum toxicity; recently a number of researchers have tried to elucidate the problem.

It has been reported that the effect of aluminum is associated with DNA synthesis in cell division. This agrees with findings that associate aluminum with the nucleic acid in root meristematic cells. This may explain why mitotic activity quickly diminishes in the presence of aluminum (5).

Using the scanning electron microscope, it has been observed that aluminum can induce several morphological changes on the root surface, such as:

- * Decrease in the turgescence of epidermal cells of the tip and elongating regions (barley).
- * The presence of a large number of small depressions, mainly on the elongating regions (oats and rice).
- * Destruction of epidermal and outer cortex cells of the tip and the elongating regions (maize).
- * Deep transversal cracks in the inner cortex cells, mainly on the elongating region (pea).

Few morphological changes have been observed in the proximal portion of the root.

An intensive study on the destruction process of plant root cells by aluminum has been conducted by Wagatsuma et al. (17). They suggest that: 1) in aluminum-sensitive plants, the destruction of the root cells involves the more proximal and the more inner cells, and 2) that the destruction of cells associated with aluminum toxicity is not restricted to the meristematic region of the root. They postulated that aluminum may bind to various sites on the plasmalemma of root cells, and, consequently, possibly inducing leakage of potassium out of the plasmalemma and passive permeation of the aluminum through the plasmalemma.

Foy et al. (7) reported different reactions of two wheat varieties, one tolerant and one sensitive to aluminum, associated with plant-induced pH changes around their roots. They found that the aluminum-tolerant variety raised the pH in a nutrient medium, while the aluminum-sensitive variety lowered the pH in the nutrient solution.

Objectives

In 1974 the International Maize and Wheat Improvement Center (CIMMYT) initiated cooperative research with the wheat programs of the Brazilian Agricultural Research Enterprise (EMBRAPA) and the Rio Grande do Sul Federation of Wheat and Soybean Cooperatives (FECOTRIGO). Later in the decade, this cooperation expanded to other Brazilian institutions, such as the Organization of Paraná State Cooperatives (OCEPAR) and the Paraná Agronomic Institute Foundation (IAPAR).

The major goal of this cooperation has been to combine the tolerance to aluminum toxicity of some Brazilian varieties with the high genetic yield potential of the Mexican wheats. Mexican wheats are highly sensitive to aluminum. In the process of combining aluminum tolerance with high genetic yield potential, the segregating populations of Mexican x Brazilian crosses are tested at four locations in Brazil for aluminum tolerance and at two locations in Mexico for yield potential. Selection for agronomic type and disease resistance is done at all six locations. This process of alternate selection in two countries is popularly known as "Shuttle Breeding." and is explained in more detail elsewhere in these proceedings.

The CIMMYT wheat breeding program utilizes aluminum-tolerant materials and segregates selected under laboratory conditions in which seedlings are exposed to a low pH nutrient solution containing high levels of aluminum. The main effect of aluminum toxicity in the nutrient solution can be clearly detected because the cell division of the apical part of the root of sensitive seedlings stops. Several methods were tested at CIMMYT's laboratory before a modified hematoxylin method (13) was adopted for screening purposes.

Methodology

Reagents

Seven different solutions are prepared for this laboratory procedure:

* Concentrated nutrient solution: Dissolve in about 900 ml of distilled water, 22.2 g of CaCl_2 anhydrous; 32.86 g of KNO_3 ; 25.41 g of $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$; 0.66 g of $(\text{NH}_4)_2\text{SO}_4$; and 1.60 g of NH_4NO_3 . Dilute to 1 liter and store at $\pm 7^\circ\text{C}$.

* 0.1 M aluminum solution: Dissolve 24.14 g of $\text{AlCl}_3 \cdot 6\text{H}_2\text{O}$ in about 900 ml of distilled water. Dilute to 1 liter and store at $\pm 7^\circ\text{C}$.

* 0.25 M HCl solution: 20.83 ml of concentrated HCl diluted to 1 liter. Store at $\pm 7^\circ\text{C}$.

* 0.2% hematoxylin solution: Dissolve 2 g of hematoxylin anhydrous in about 900 ml distilled water; add 0.2 g NaIO₃ and dilute to 1 liter of volume.

* Nutrient solution: Place 760 ml of distilled water in a plastic container, add 240 ml of the concentrated nutrient solution prepared above, then add 11 liters of distilled water. Mix and adjust the pH to 4.0 using the 0.25 M HCl solution prepared above. The resulting concentration is: 4 mM of CaCl₂; 6.5 mM of KNO₃; 2.5 mM of MgCl₂·6H₂O; 0.1 mM of (NH₄)₂SO₄; and NH₄NO₃

* Nutritive solution containing aluminum: This 1.7 mM solution equal to 46 ppm of aluminum is prepared by mixing 760 ml distilled water, 240 ml of concentrated nutrient solution prepared above, 204 ml of the 0.1 M aluminum solution prepared above and then diluting to 12 liters of distilled water. Adjust the pH to 4.0.

* 10% sodium hypochlorite solution.

Procedure

With the following procedure, thousands of advanced lines and segregating populations are evaluated each year.

Wheat seeds are sterilized with the 10% sodium hypochlorite solution for 1 minute and rinsed thoroughly with water. The soaked seeds are then placed on wet filter paper in Petri dishes and kept at $\pm 7^{\circ}\text{C}$ for approximately 65 hours.

The seeds in the Petri are left to germinate at room temperature (18-20°C) for approximately 24 hours. The sprouted seeds are placed on a polyethylene net that has been fixed in lucite frames. Styrofoam blocks are attached to the frames with rubberbands and floated on the surface of nutrient solution in containers. These are placed in a water bath maintained at 25°C and exposed to intervals of 8 hours of incandescent light, 16 hours without light. Four planting trays with 60 squares and 4 seeds per square are placed in each container holding 12 liters of nutrient solution. Two check varieties (one tolerant and one sensitive to 46 ppm of aluminum) are included in each tray.

After the seedlings have grown for 32 hours in the nutrient solution, they are transferred to the nutrient solution with 46 ppm of aluminum, which has a pH of 4.0 and maintained at 25°C. This is continually aerated for 17 hours.

After 17 hours, the roots are removed from the nutrient solution with aluminum and thoroughly washed for 2-3 minutes in running tap water and then stained with the 0.2% hematoxylin aqueous solution for 15 minutes. The excess dye is then washed off with distilled water.

The seedlings are then returned to the containers with distilled water and the nutrient solution at 25°C and continuously aerated as before for approximately 24 hours.

Finally, the seedlings are evaluated on a 1-3 scale: 1 (sensitive), 2 (medium-tolerant); and 3 (tolerant). Figure 1 shows the seedlings with the corresponding classifications after 24 hours of recovery in nutrient solution. Continued growth of the tolerant seedlings can be easily assessed. The roots of susceptible seedlings do not continue growing because the meristems have been irreversibly damaged.

The material screened in the laboratory usually includes segregating F_2 , F_3 , F_4 , F_5 , F_6 , F_7 , and F_8 lines, as well as elite materials and the advanced lines originating from Aluminum segregating populations. The advanced lines selected in the laboratory are transplanted to pots for growing in the greenhouse and later multiplied in the field and distributed to cooperators as the Aluminum Tolerance Screening Nursery. Tolerant varieties have been released in Brazil, Mexico, Madagascar, and Zambia.

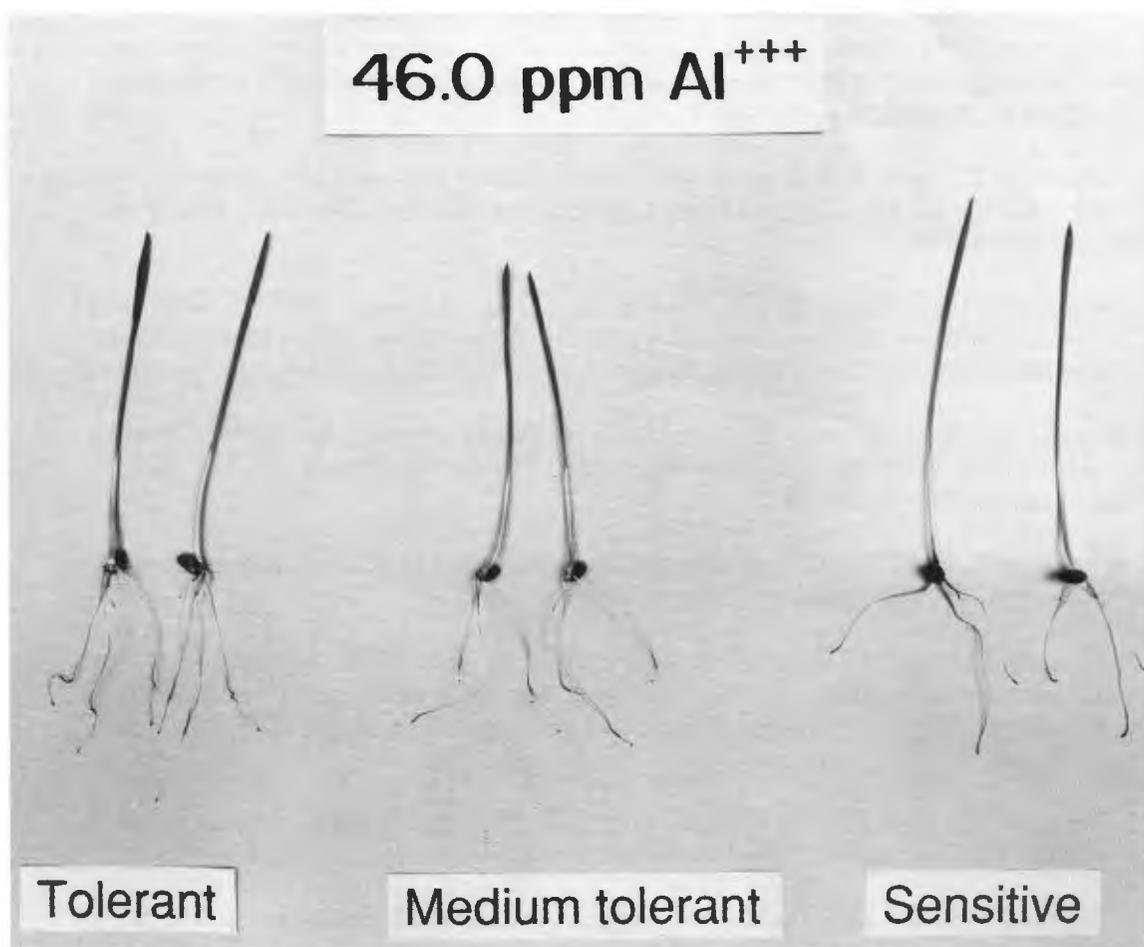


Figure 1. Roots of wheat seedlings showing tolerant, medium-tolerant, and sensitive responses to aluminum after 24 hours of recovery in nutrient solution.

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THE BRAZILIAN INSTITUTIONS THAT COLLABORATE WITH CIMMYT

CIMMYT collaborates with a number of Brazilian agricultural research institutions (see map), which are supported by the Federal government, state governments, and farmer cooperatives.

Brazilian Agricultural Research Enterprise

The Brazilian Agricultural Research Enterprise (EMBRAPA), founded in 1974, is the USDA of Brazil. However, unlike in the United States where most USDA staff are assigned to universities where they do research on special projects, EMBRAPA is set up like the Consultative Group on International Agricultural Research (CGIAR) system. There are seven EMBRAPA commodity centers one of which is The National Research Center for Wheat (CNPT) in Passo Fundo, Rio Grande do Sul. A second group of EMBRAPA institutions are resource centers, such as the Cerrados Agricultural Research Center (CPAC), which work with crops, pastures, and livestock to develop an integrated agricultural system for a particular region. EMBRAPA also has regional service centers that deal with germplasm conservation, chemical pesticide control, biotechnology, etc.

State-Supported Institutions

Virtually all Brazilian states have their own agricultural research institutions. In the states that have no research organizations, EMBRAPA has opened experimental units to do the research there. State institutions with which CIMMYT collaborates include the Campinas (in the state of São Paulo) Agronomic Institute (IAC), the Paraná Agronomic Institute Foundation (IAPAR), and the Minas Gerais Enterprise of Plant and Animal Research (EPAMIG). IAC, which will be celebrating the 100th anniversary of its founding in 1987, was the first truly successful research institute of its kind in Latin America.

Cooperative-Supported Institutions

Cooperative-supported institutions also play important research roles. Farmers contribute a certain percentage (usually 0.2 to 0.4%) of their income from soybean and wheat harvests. This money goes straight to the cooperatives' research arms, such as the Research and Experimental Center (CÉP) of the Rio Grande do Sul Federation of Wheat and Soybean Cooperatives (FECOTRIGO) and the Eloy Gomes Research Center of the Organization of Paraná State Cooperatives (OCEPAR).

FECOTRIGO has the longest history of collaboration with CIMMYT, dating back to the early 1970s when germplasm exchange between Brazil and Mexico began with a degree of regularity.



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